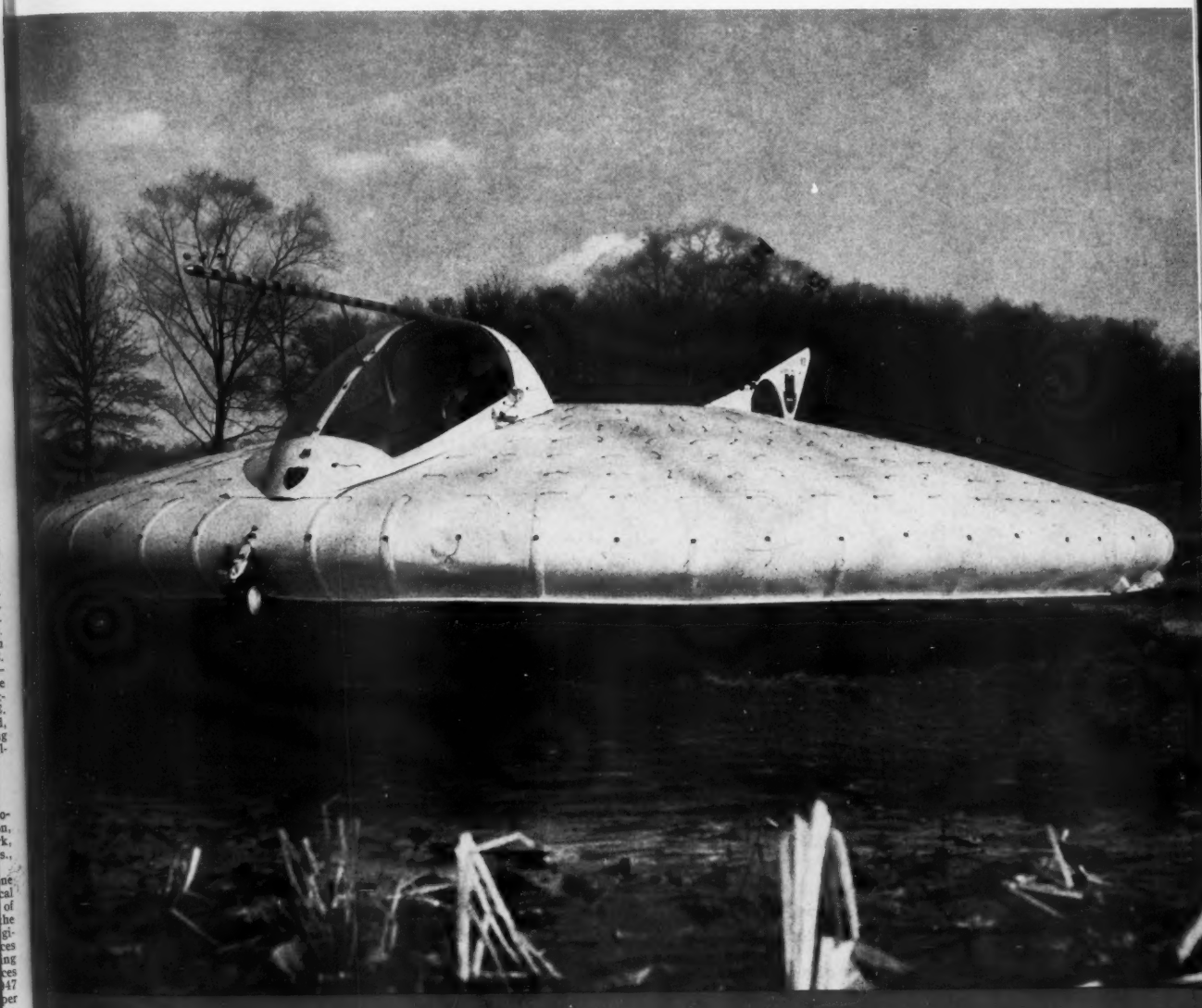
INSTITUTE OF THE AERONAUTICAL SCIENCES

AERO/SPACE ENGINEERING

REVIEW OF CURRENT AND FUTURE TRENDS IN AIRCRAFT • MISSILES • ROCKETS • SATELLITES • SPACECRAFT



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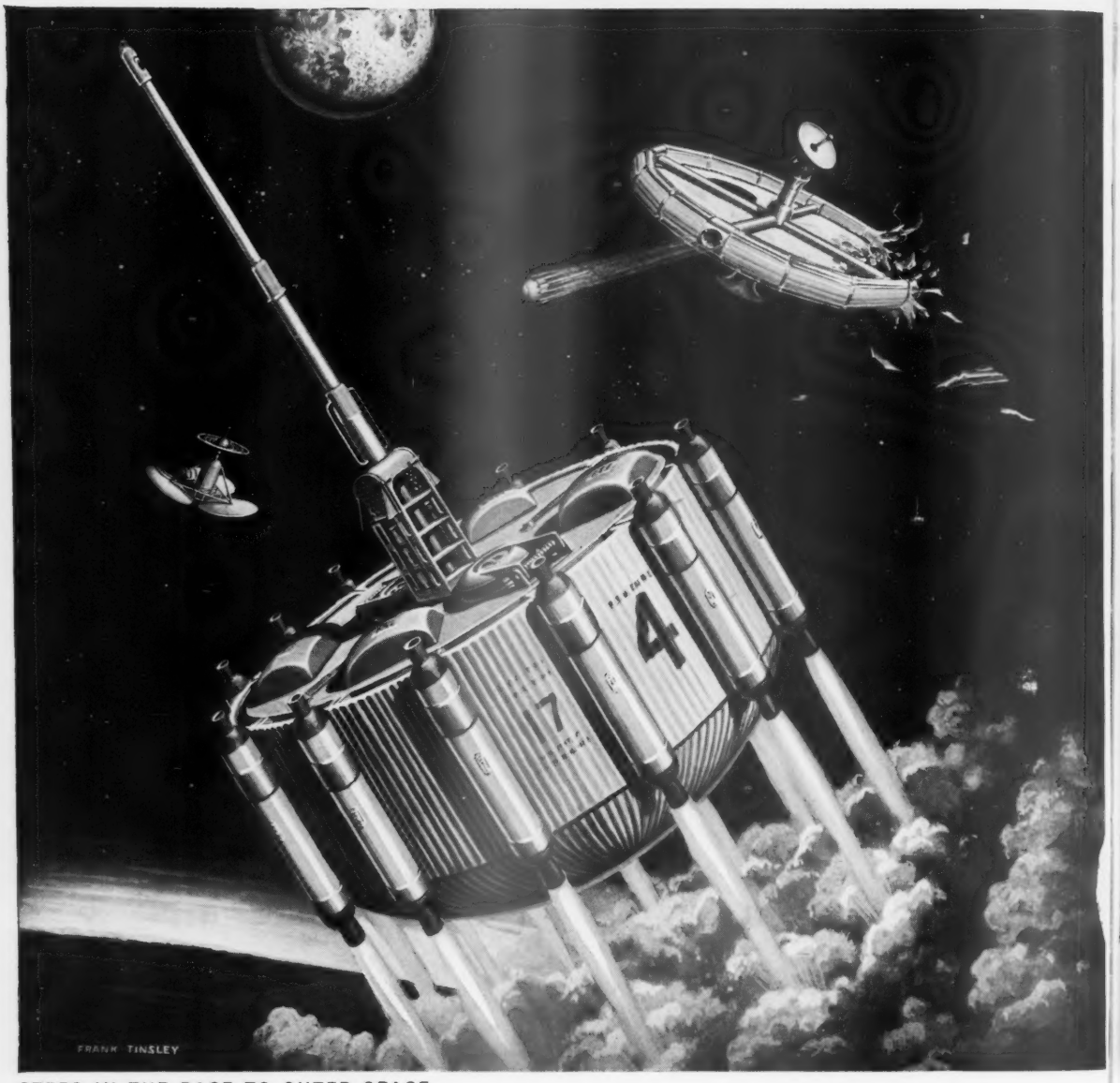
EDITORIAL: *A Policy Statement . . . p. 30*

APRIL / 1960



STEPS IN THE RACE TO OUTER SPACE

Escape In Space

The space-assembled super satellites of the future will periodically encounter disaster—collision, mechanical failure, military attack, or the long chance of being hit by a meteorite. When this happens, "life boats" like the one shown here will bring their crews safely back to earth.

Here is the operational sequence of an escape in space:

1. Crew members don pressure suits and strap themselves into decelleration beds within the pressure-intact unit.

2. At the "Abandon Ship" signal, low-power, RATO-type launching rockets blast the sealed capsule from the threatened station (upper right illustration).

3. Acting on orders from an astrogational computer, the retro-rockets check the capsule's speed and break it out of orbit. (Foreground. Note details of offset heat shielding, hatches, slow-down parachute covers.)

4. As the capsule enters the outer atmosphere, the heat shield protects the astronauts. The life boat's momentum slows even further, and the shield is jettisoned as it cools.

5. Four parachutes are released, acting as air brakes. After a computed interval, other chutes are released.

6. The capsule lands in a predetermined sea rescue area, and a ring of flotation bags inflate. A radio broadcasts the craft's location, and a bright sunshade serves as a visual and radar target for rescuers.

ARMA, now providing the inertial guidance system for the ATLAS ICBM and engaged in advanced research and development, is in the vanguard of the race to outer space. For this effort, ***ARMA*** needs scientists and engineers experienced in astronautics. ***ARMA***, Garden City, New York. A Division of American Bosch Arma Corporation.

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AERO/SPACE ENGINEERING

VOLUME 19 / NUMBER 4 **April 1960**

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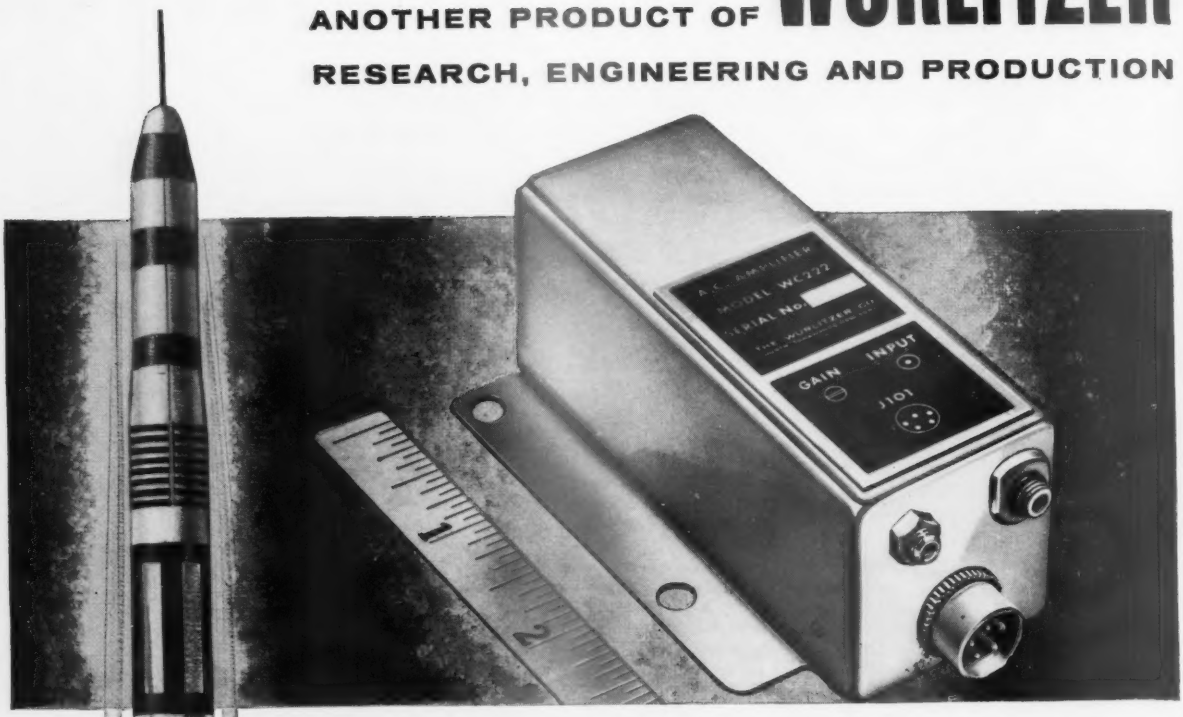

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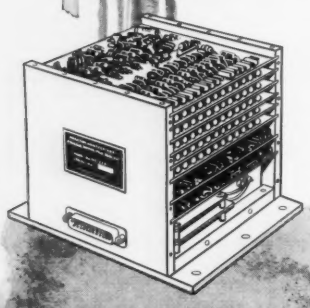

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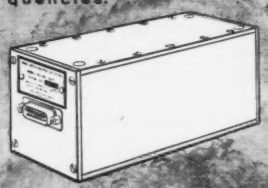

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LETTERS to the Editor

Discus Body/Rocket Launching System

■ With considerable interest I read Martin Gerloff's article on the discus body in your January issue. I believe that a very economical satellite launching system could be built using such a device for the first stage, and a rocket for the second stage. The rocket would be carried in a groove in the underside of the discus, so mounted that it could contribute thrust. Take-off would be horizontal, using the rocket for propulsion. When sufficient velocity for ram-jet operation is attained, the rocket would be shut down, and the system would continue on ram-jet power. When the system reaches the maximum velocity allowed by aerodynamic heating, the rocket would be restarted, the propellant tanks of the rocket would be topped off from tanks in the discus, and the rocket would be released. It would accelerate to orbit while the discus returns to earth.

Ed Miksch
Graduate Student
Harvard University

Dr. Gerloff Replies

■ I quite agree with Mr. Miksch's thoughts. The achievement of an "operational" booster system and a much better power efficiency appears to be the real challenge in future space mission design.

The present state of development of ballistic space exploration does not seem to represent a sufficient solution for the safe re-entry of a man-carrying satellite or for an operational space system. Wing-shaped space vehicles will be required, and present-day multistage rockets do not have enough inherent stability to stand the destabilizing effect.

I also prefer the horizontal take-off. Much could be gained in movability and reliability. Our development of missile-firing from silos can be compared to the creation of the Maginot line which history has proved not worth the effort.

An operation against aerodynamic heating may be avoided by a properly selected lift efficiency and q-path. Nobody would use a submarine for speeding but a glide boat.

Besides boosting an orbital payload—since a ship on water is by far the cheapest means of transportation—it can be visualized that future traffic may well be handled with low loaded aerodynamic bodies (inflatable discus) planing on top of the air layers. In spite of velocities of $M = 3$ to 5, the passengers will enjoy the lighter-than-air luxury of the rigid airships of 1936.

Summing Up

(1) A recoverable booster could cover both of the following—present missile systems would be improved, and the first-stage booster would represent an efficient tactical bomber for SAC.

(2) The propulsion unit for a missile must generate a thrust of about 1.3 to 1.4 times the gross weight; a winged booster could operate with a thrust of 0.4 to 0.5 times the gross weight performing the same acceleration.

(3) The recoverable booster may cut the costs of space flight and make the space mission operational.

(4) The horizontal take-off simplifies launching procedure and increases reliability and movability. There is no danger of expended boosters falling into inappropriate areas.

Martin Gerloff, MIAS
General Electric Co.

✦ ✦ ✦

Remarks and Replies: "Optimum Rocket Trajectories"

■ A paper dealing with maximum altitude trajectories[1] appeared in the January issue of AERO/SPACE ENGINEERING. At first glance, the solution obtained by the authors of reference 1 appears to be simpler than solutions obtained by other investigators of similar problems. However, this impression proves to be illusory since there is a fundamental error in the analysis.

Using the nomenclature of reference 1, we see that there are *five* dependent variables V_a, γ_1, h_a, θ, and α. Also there are *four* side conditions connecting these variables, two kinematic and two dynamic ones. Furthermore, the end values of time t as well as of V_a, γ_1, and θ are prescribed. It is desired to find that trajectory—i.e., the functions $V_a(t)$, $\gamma_1(t)$, $h_a(t)$, $\theta(t)$, and $\alpha(t)$—which results in a maximum increase in height $h_a(t_2) - h_a(t_1)$.

If the problem is treated as a classical Lagrange problem (cf. references 2 or 3), then one must find extremals for the maximum of

$$h_a(t_2) - h_a(t_1) = \int_{t_1}^{t_2} V_a \sin \gamma_1 \, dt \qquad (1)$$

subject to *four* side conditions and the end conditions. Thus one seeks the extremum of a functional

$$J \equiv \int_{t_1}^{t_2} \left[V_a \sin \gamma_1 + \sum_{i=1}^{4} \lambda_i(t)\phi_i \right] dt \qquad (2)$$

where

$$\phi_i = 0, \qquad i = 1, 2, \ldots 4 \qquad (3)$$

stand for the side conditions. The vanishing of the first variation of J will then give rise to *five* Euler-Lagrange equations involving *four* undetermined multipliers $\lambda_i(t)$, $i = 1, \ldots 4$. It should be noted that *the kinematic constraint on h_a must be included* since h_a occurs in the integrand of Eq. (2) via the dependence of g and $\dot{\theta}$ on h_a.

Of course, one can eliminate α and $\dot{\theta}$ by means of side conditions—Eq. (3)—as was done in reference 1. In that case, there still remain *two* side conditions involving V_a, γ_1, and h_a. Hence *two* Lagrange multipliers must be used to adjoin the side conditions to $V_a \sin \gamma_1$. Now there arise only *three* Euler-Lagrange equations. However, these are completely equivalent to those obtained by extremizing J of Eq. (2).

The authors of reference 1 have failed to account for the constraint on $\dot{h}_a$; consequently, they arrive at only *two* Euler-Lagrange equations involving only *one* undetermined multiplier. The extremals arising from their formulation are *not* the extremals of the problem as stated.

References

[1] Dommash, D. O., and Barron, R. L., *Optimum Rocket Trajectories. Part I—Initial Value Variational Solutions,* Aero/Space Engineering, Jan., 1960.

[2] Bolza, O., *Vorlesungen über Variationsrechnung,* Koehler und Amelang, Leipzig, 1949.

[3] Bliss, G. A., *Lectures on the Calculus of Variations;* University of Chicago Press, Chicago, 1946.

G. Leitmann
Assoc. Prof., Engrg. Science
Univ. of California, Berkeley

Mr. Dommasch Replies

■ The following is in reply to Leitmann's letter about our paper in the January issue of AERO/SPACE ENGINEERING. We appreciate Leitmann's desire to defend the discontinuous "subarc" solutions to optimum problems presented in his paper "On a Class of Variational Problems in Rocket Flight" which appeared in the September, 1959, issue of the JOURNAL OF THE AERO/SPACE SCIENCES. It should be quite clear, however, that from a physical standpoint the Leitmann solutions are quite unreal, and that the error in Leitmann's reasoning arises from the assumption that a problem with but two physical degrees of freedom requires three Euler equations for its definition. Evidently, if there are but two degrees of freedom, the introduction of a third (which actually is defined in terms of the other two) does not have physical reality. Specifically, since

$$\dot{h}_a = V_a \sin \gamma_1$$

once variations on V_a and γ_1 are prescribed, it is clear that $\dot{h}_a$ and hence h_a are no longer free, and indeed are uniquely specified independent of any other consideration.

The proper formulation of any Euler-Lagrange problem requires sufficient Euler

relations to define the real freedoms in the problem. It does not require the introduction of hypothetical freedoms as implied by Leitmann *et al.* Moreover, any attempt to introduce nonexistent restraints produces a degraded solution (in the event that any solution remains).

As stated in our paper, the nature of the restraints imposed must be fully comprehended or serious errors can be introduced; moreover, it is axiomatic that excessive restraints restrict rather than generalize a solution.

On the basis of the foregoing, Leitmann's stipulations are in error, and we again conclude that the equations of our paper are *entirely correct and do define the desired class of optimums* insofar as the Euler-Lagrange relations are concerned. We must add, however, that the Euler-Lagrange relations are necessary, but not sufficient, conditions, and therefore only through numerical investigation is it established that these relations do, in fact, produce real optimum solutions.

Since these numerical studies have been carried out, we have obtained the required sufficiency condition, as well as unassailable proof of the validity of our methodology. We do not believe that sufficiency conditions exist to justify the Leitmann approach.

Daniel O. Dommasch, AFIAS
Pres., DODCO, Inc.
Blawenburg, N.J.

A Further Comment

■ I wish to comment on the variational treatment of maximum altitude trajectories published recently in *A/SE* by Dommasch and Barron.[1] There is a mistake of a basic nature in this work, arising from improper application of the Euler-Lagrange equations of the indirect variational theory.

For clarity I will employ the notation of reference 1 and begin by reviewing the usual Lagrange formulation of this problem.

A maximum of the integral

$$h_G = h_a(t_2) - h_a(t_1) = \int_{t_1}^{t_2} V_a \sin \gamma_1 dt \quad (1)$$

for altitude gained over the time interval t_1 to t_2 is sought, along with the functions upon which it depends. In the planar case considered, these are

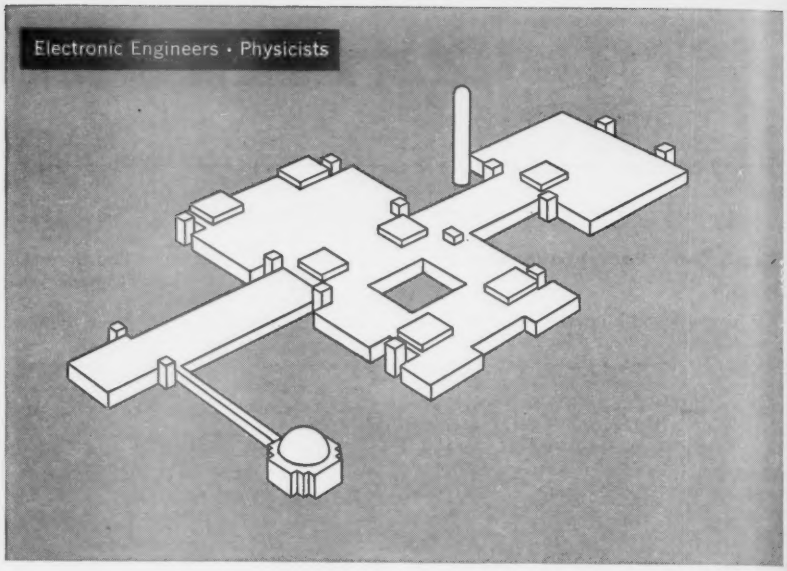
$V_a(t)$ = velocity magnitude
$\gamma_1(t)$ = flight path angle
$h_a(t)$ = altitude measured from earth center
$\theta(t)$ = range angle
$\alpha(t)$ = angle between thrust line and velocity vector

The integral is to be made stationary subject to the following equations of motion and kinematic relations as subsidiary conditions of the extremum problem:

Acceleration Tangential to Flight Path

$$G_1 = F_e \cos \alpha - m\dot{V}_a - mg \sin \gamma_1 = 0 \quad (2)$$

(*Continued on page 108*)



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the Green Sheet

IAS BULLETINS AND LATE NEWS...

April 1960

AERO/SPACE ENGINEERING readers may look forward to a history-making magazine next month. The original works of 55 aerospace engineers and scientists in the field of Manned Space Stations will be published, thus bringing together for the first time anywhere a wealth of data hitherto unavailable under one cover.

THE NATIONAL TELEMETERING CONFERENCE, cosponsored by the IAS, AIEE, ARS, ISA, and IRE, is to be held May 23-25 at the Miramar Hotel in Santa Monica, Calif. Sixteen technical sessions consisting of 71 papers, 2 workshop sessions, exhibits, trips, luncheons and a banquet make up the program for this year's conference, theme of which is "Telemetry—Tool for Industry". Individuals wishing further information should contact Hugh Pruss, Chairman, National Telemetering Conf., c/o Telemetering Corp. of America, 8345 Hayvenhurst Ave., Sepulveda, Calif. Phone: EMpire 2-3131.

IAS FLIGHT TEST FELLOWSHIP WINNER FOR 1960 IS HARRY PASSMORE, III, of Ft. Worth, Tex. Mr. Passmore, an Aeronautical Engineering graduate of Georgia Tech, is employed by Convair-Ft. Worth, and taking graduate courses at Southern Methodist University.

DR. IGOR SIKORSKY WILL PRESENT THE SECOND LESTER D. GARDNER LECTURE in MIT's Kresge Auditorium, 3:30 p.m., Thursday, April 14. Dr. Sikorsky, an Honorary Fellow of the IAS, will discuss "Pioneering in Aircraft". All are invited.

KEYNOTE SPEAKERS FOR IAS STUDENT REGIONAL CONFERENCES include James B. Reichert, Aerodynamicist and Chief Test Pilot for Doak Aircraft Co., who spoke at the West Coast Conference in Los Angeles, March 31-April 1. Dr. Alexander H. Flax, Chief Scientist, USAF, will address the Northeastern Conference at Brooklyn Poly, April 9; Dr. E. R. Sharp, Director of NASA's Lewis Research Center in Cleveland, will be guest speaker at the Southeastern Conference in Atlanta, Georgia, May 5-6; Dr. Jerome Lederer, Director of the Cornell-Guggenheim Aviation Safety Center, will be the speaker at the Middle-Atlantic Conference in Morgantown, West Virginia, April 29-30.

MANNED SPACE STATIONS SYMPOSIUM COMMITTEE has made arrangements to accommodate between 700 to 1,000 at this IAS-NASA-RAND sponsored meeting to be held April 20-22 at the Ambassador Hotel in Los Angeles.

THE APPOINTMENT OF DR. COURTLAND D. PERKINS, FIAS, AS ASSISTANT SECRETARY OF THE AIR FORCE FOR RESEARCH AND DEVELOPMENT HAS RECEIVED CONGRESSIONAL APPROVAL.

SECTION MEETINGS CALENDAR*

Apr. 2 Los Angeles: Historical Meeting, IAS Bldg., 8 pm, "A Tribute to Roy Knabenshue", Chmn: Gen. F. Lahm & A. E. Raymond; Films: Zeno Klinker.

Apr. 5 Detroit: Space Meeting, Engineering Society of Detroit, 6 pm, "Ancillary Systems for Space Vehicles", Kurt Stehling, NASA.

Apr. 12 Boston: General Meeting, Rm. 2-190, MIT, 8 pm, "Soviet Aviation Today", R. P. Alex, Sikorsky Aircraft, and President, American Helicopter Society.

Apr. 12 Los Angeles: Specialists Meeting, IAS Bldg., 8 pm, "Measurement of Temperature and Pressure in the Upper Atmosphere", Charles Barth, JPL, CIT.

Apr. 12 New Mexico: Dinner Meeting, Officers' Club, Kirtland AFB, 7 pm, "Supersonic Transports", James B. Colburn.

Apr. 13 Niagara Frontier: Specialists Meeting, Auditorium, Cornell Aero. Lab, 8 pm, "The Aerodynamic Appraisal of STOL/VTOL Configurations", Robert J. Vidal, CAL.

Apr. 13 Chicago: Annual Student Meeting, Illinois Institute of Tech., 7:30 pm, "Future of Aeronautical Engineers", Panel of 3 speakers.

Apr. 14 Twin Cities: Dinner Meeting, Main Ballroom, Curtis Hotel (Minneapolis), 6 pm, "Man's Venture into Space", James Van Allen, State Univ. of Iowa.

Apr. 19 Cleveland-Akron: Tour of Babcock & Wilcox, 4 pm, Dinner Meeting, Iacomini's Restaurant, 6 pm, "Applications of Expandable Structures to Space and Re-entry", R. S. Ross.

Apr. 20 Columbus: Dinner Meeting, "Some Consideration in the Design of V/STOL Aircraft", R. G. Loewy, Vertol Aircraft Corp.; for time and location, contact R. D. Best, 3821 Mann Road, Blacklick, Ohio.

Apr. 21 Indianapolis: Technical Meeting—Pizza Feast, Columbia Park, 7 pm, "National Survival", Col. Roscoe Turner.

Apr. 26 Los Angeles: Specialists Meeting, IAS Bldg., 8 pm, "Space Explorations", Fred Eimer, Jet Propulsion Lab., CIT.

Apr. 30 Niagara Frontier: Spring Dance, Buffalo Yacht Club, 10 pm.

May 10 Los Angeles: Specialists Meeting, IAS Bldg., 8 pm, "Meteorites", Prof. Harrison Brown, CIT.

May 19 Los Angeles: Dinner Meeting, IAS Bldg., 6 pm, Family Night Smorgasbord, "The X-15 Story", A. Scott Crossfield, North American Aviation.

May 19 New York: Dinner Meeting, Airborne Instruments Lab. Deer Park Cafeteria, 6:15 pm, Col. Carlo R. Tosti, USAF, Headquarters ARDC.

May 24 Los Angeles: Specialists Meeting, IAS Bldg., 8 pm, "Magneto-Hydrodynamic Experiments", V. H. Blackman, MHD Research, Inc.

June 14 Los Angeles: Specialists Meeting, IAS Bldg., 8 pm, "Bi-axial Stress Fields", D. Fitzgibbon.

Aug. 29-30 Los Angeles: Section Symposium, IAS Bldg., all day, "Recovery of Space Vehicles"—including Secret sessions.

* Items for this section accepted up to seven working days before end of the month.

INTERNATIONAL, NATIONAL, AND JOINT MEETINGS CALENDAR

Apr. 20-22	Symposium on Manned Space Stations (cosponsored by NASA and The RAND Corp.), Ambassador Hotel, Los Angeles, Calif.
May 2-4	IRE Aeronautical Electronics Conference (Participation by Dayton Section of IAS), Dayton, Ohio.
May 23-25	National Telemetering Conference (cosponsored by IAS, ISA, ARS, IRE, and AIEE), Hotel Miramar, Santa Monica, Calif.
May 25-27	Specialists Meeting, Guidance of Aerospace Vehicles, Boston, Mass.
June 28-Jul. 1	Summer Meeting, Ambassador Hotel, Los Angeles, Calif.
Aug. 1-3	Meeting on Future of Manned Military Aircraft, San Diego, Calif.
Sept. 12-16	2nd International Congress, International Council of the Aeronautical Sciences, Zurich, Switzerland.
Oct. 3-5	Midwestern Conference on Air Logistics, Tulsa, Okla.
Oct. 17-18	CAI/IAS Joint Meeting, Queen Elizabeth Hotel, Montreal, Canada.
Oct. 20-21	Symposium on Hypervelocity Techniques, Denver, Colorado.
Dec. 17	Wright Brothers Lecture, Washington, D.C.
1961	
Jan. 23-25	29th Annual Meeting, Hotel Astor, Times Square, New York.
Mar. 9-10	Flight Propulsion Meeting (Classified), Cleveland, Ohio.

IAS News

. . . a record of people and events of interest to Institute Members

Guidance of Aerospace Vehicles Symposium Scheduled for Boston May 25–27

3-Day Forum for Exchange of Latest Technical Information Will Include Address by C. S. Draper on Future Concepts

TRAJECTORY ANALYSIS, optical techniques, digital simulation, and human attitude control are among discussion areas scheduled for the IAS National Symposium on Guidance of Aerospace Vehicles, May 25–27, at the Somerset Hotel in Boston, Mass. A full program consisting of six technical sessions, a luncheon, and a reception-dinner has been planned. The Institute's Boston Section is handling all arrangements; a detailed program has been prepared for individual mailing to members.

Dr. Charles S. Draper, Head of the Department of Aeronautics and Astronautics of M.I.T., will be speaker at the luncheon on Wednesday, May 25. Dr. Draper, an IAS Honorary Fellow, will discuss "Guidance Concepts of the Future." The speaker for the dinner on Thursday, May 26, will be announced.

The Meeting Committee, composed of members of the Boston Section, is headed by Section Chairman Daniel J. Fink, Vice-President and Chief Engineer, and Technical Program Chairman William B. Bryant, Manager, Systems Engineering Div., both of Allied Research Associates, Inc. Lawrence E. Beckley, Associate Director of M.I.T.'s Instrumentation Laboratory, is Arrangements Chairman.

Technical papers will be presented as follows:

May 25

Guidance for Satellite Missions (A.M.)

"Mission Planning and Tactics for an Air-Launched Satellite Reconnaissance Missile"—D. J. Simmons, Convair-Ft. Worth, Div. of General Dynamics Corp.

"Some Considerations of Guidance and Control Techniques of Coplanar Orbital Rendezvous"—E. Harrison and M. Barnett, Vought Astronautics Div., Chance Vought Aircraft, Inc.

"The Long-Time Satellite Rendezvous Trajectory"—Louis W. Spradlin, M.I.T. Instrumentation Lab.

"Control and Guidance of Point Return Vehicles"—J. H. Lowry and C. D. Buehrle, Vought Astronautics Div., Chance Vought Aircraft, Inc.

Mechanization Techniques (P.M.)

"Horizon Sensors for Vertical Stabilization of Satellites and Space Vehicles"—Morris H. Arck and M. Monte Merlen, Barnes Engineering Co.

"An Accurate Determination of Attitude by Optical Means"—G. von Pahlen-Federoff, Advanced Systems, The Martin Co., Orlando.

"Application of Optical Techniques to Interplanetary Navigation"—Wesley J. Haywood, Jr., Missile Systems Div., Raytheon Co.

"A Free Reaction Sphere Satellite Attitude Control System"—R. D. Ormsby, Systems Div., Bendix Aviation Corp.

"A Magnetic Bearing Suspension for Floated Integrating Gyros and Pendulous Accelerometers for Inertial Guidance Systems"—P. J. Gilinson, Jr., W. G. Denhard, and R. H. Frazier, M.I.T. Instrumentation Lab.

Charles S. Draper
Luncheon Speaker

William B. Bryant
Technical Program Chairman

May 26

Attitude Control (A.M.)

"Measurement of Controller Parameters for an Adaptive Autopilot"—Charles A. Harvey and Judson A. Lovingood, Aeronautical Div., Minneapolis-Honeywell Regulator Co.

"Limit Cycle Efficiency of On-Off Reaction Control Systems"—George Freeman, Aero-Space Div., Boeing Airplane Co.

"A Study of an Adaptive Control System Using Digital Simulation"—T. R. Benedict, H. R. Leland, W. C. Schultz, and M. G. Spooner, Cornell Aeronautical Lab., Inc.

"V/H Attitude Control of Satellites"—P. E. Mallory and P. A. Button, Research Div., Radiation, Inc.

Special Problems in Guidance and Control (P.M.)

"Control Development for Jet VTOL"—James A. O'Malley, Jr., Aero-Space Dept., Bell Aircraft Corp.

"In-Flight Measurement of Human Operator Alertness"—Thomas B. Sheridan, Dynamic Analysis and Control Lab., M.I.T.

"Pilot Control of Space Vehicle Attitude"—James W. Useller and Joseph S. Algranti, Lewis Research Center, NASA.

"Hovering and Longitudinal Dynamics of the Ground Effect Machine With Derivations of the Stability Derivatives for Vertical Motion"—Tsun-Ying Feng, Bell Aircraft Corp.

May 27

Lunar and Interplanetary Guidance (A.M.)

"Parameter Sensitivity and Guidance Viewpoints for Circum-Lunar-Flight and Return"—R. F. Hoelker, N. J. Braud, O. C. Jean, and A. J. Schwaniger, Army Ballistic Missile Agency.

"Trajectory Problems in Cislunar Space"—George Shapiro, Astronautics Institute, Air Arm Div., Westinghouse Electric Corp.

"Terminal Guidance for Lunar and Planetary Probes"—R. H. Grube, Aerojet-General Corp.

"Differential Correction Method of Interplanetary Navigation"—Harvey Safren, The Martin Co., Baltimore.

Analytical Techniques (P.M.)

"Methods of Analysis of a Control System for a Large Flexible Missile"—David R. Lukens, Convair-Astronautics, Div. of General Dynamics Corp.

"Application of Adaptive Control Techniques to Aero/Space Vehicles"—W. F. O'Neil and M. J. Abzug, Douglas Aircraft Co., Inc.

"Graphical Trajectory Analysis"—Aaron S. Boksenbom, Lewis Research Center, NASA.

"Prediction of Anisoelastic and Vibropendulous Effects on Inertial Navigation System Performance in Random Vibration Environments"—Samuel Leshnover, Aeronautical Div., Minneapolis-Honeywell Regulator Co.

A. Scott Crossfield Receives AAS Flight Award

A. Scott Crossfield (AF), Chief Test Pilot for North American Aviation Corp.'s Los Angeles Div., was presented with the annual Flight Achievement Award of the American Astronautical Society at its annual meeting in New York late in January. The award was given to Mr. Crossfield for his contributions to the progress of manned space flight and cited him as: "The man whose skill, courage, and dedication to manned rocket flight have shown the way to travel beyond the conventional flight regime. A pioneer in the testing of high-performance advanced research craft, his engineering knowledge and cool skill under difficult circumstances have contributed greatly to man's efforts to extend the frontiers of flight from the earth's environment into space."

IAS *News* — *News of Members*

H. Norman Abramson (AF), formerly Manager of Engineering Mechanics, has been appointed Director of Applied Mechanics for Southwest Research Institute.

David Blair (A), Chief, Research and Development, Robinson Technical Products, Inc., has been assigned the additional duties of Assistant Chief Engineer of the company's West Coast Engineering Office.

W. Wai Chao (M) has been appointed Chief of Research at Vickers Incorporated, a Division of Sperry Rand Corp. Dr. Chao was formerly with the Space Flight and Missiles Division of Bell Aircraft Corp.

Robert C. Curry (M) has been appointed Field Service Engineer, 707-123 Technical Services Group for American Airlines, Inc. in Los Angeles. Mr. Curry was previously Project Engineer, Aircraft Structures, for the airline, based in Tulsa.

John W. Drebinger (M) has joined the Senior Staff of Ramo-Wooldridge, a division of Thompson Ramo Wooldridge Inc., as a member of the Systems Technology Dept. Dr. Drebinger was previously with Hughes Aircraft Co.

Leigh E. Dunn (AF) has been named Director of Facilities Engineering with Marquardt Corporation's new Facilities Engineering Division. Mr. Dunn will continue as Director of the Test Division.

James C. Elms (M), formerly Vice-President of Ground Electronics and Communications of Avco Corporation's Crosley Division, has been named to fill the newly created position of Vice-President and General Manager (Defense Operations) at the Division.

A. P. Fontaine (AF), a Director of Bendix Aviation Corp. and a member of its administration committee, has been elected an Executive Vice-President, responsible for engineering and research, sales, planning, product development, and patent activities.

Lucian J. Hunt (M) has been elected Vice-President in charge of American Airlines' Jet Maintenance and Engineering Center. Before his recent retirement from the Navy, he was in charge of the Naval overhaul and repair base at Coronado, Calif.

John P. Lawler (A) has been assigned duties as Vice-President of the Eastern Regional Office, including Washington, D.C. and Dayton, Ohio, of Aeronca Manufacturing Corp. He was previously Vice-President of the Washington office.

Paul M. Leland (M), formerly Administrative Scientist for Rosemount Aeronautical Labs., University of Minnesota, now is associated with the Planning Staff, Military Products Group, Minneapolis-Honeywell Regulator Co. Mr. Leland is Chairman of the IAS Twin Cities Section.

Joseph Neustein (M) has joined Electro-Optical Systems, Inc. as Head of the Advanced Power Systems Dept. of the Energy Research Division. Dr. Neustein was previously with Aeronutronic Division of Ford Motor Co. as Manager of Engine Research, Space Technology.

Norman W. Padden (M) has joined The Narda Ultrasonics Corp. as special Representative to the aircraft industry, airlines, and the Air Force. He was formerly Northeast sales representative for the Aircraft Division of Aro Equipment Corp.

Roy J. Sandstrom (AF) has been appointed General Manager of Bendix Aviation Corporation's System Division.

Benjamin Barish (M), formerly Chief Engineer for Ground Equipment Development, has been named Head of the new Project Management Dept. in the Tapco Group of Thompson Ramo Wooldridge Inc.

Lloyd R. Everingham (M) has been appointed Director of the Ryan Aeronautical Co. Space Laboratory. Mr. Everingham was formerly Vice-President in charge of Research for Radiation, Inc.

Marquardt/Ogden delivered its first production engine to the Air Force in June 1957, one month ahead of schedule. This was achieved despite the problems of creating, building and implementing a modern production facility and staffing it with qualified engineers and technical personnel. In the more than two years since, each and every delivery has been as-per-contract-schedule, while Ogden ramjets have proved 100% reliable in all test flights of Bomarc IM-99A.

By strict adherence to a realistic learning curve, Ogden Division currently delivers its supersonic ramjets at far less than their mid-1957 delivered cost—this despite the ramjet engine system's relatively early stage of maturity.

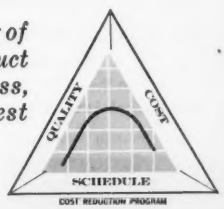
Recent expansion and additions further enhance Marquardt/Ogden's capability. In 1958 the plant doubled floor space to almost ¼ million square feet, with numbers of employees increasing 93%. 1959 marked Ogden Division's addition of a first-of-its-kind Spin Forge and completion of a new facility for explosive metal forming. Ogden's USAF-Marquardt acceptance test facility at Little Mountain gives the Division full-plant capability.

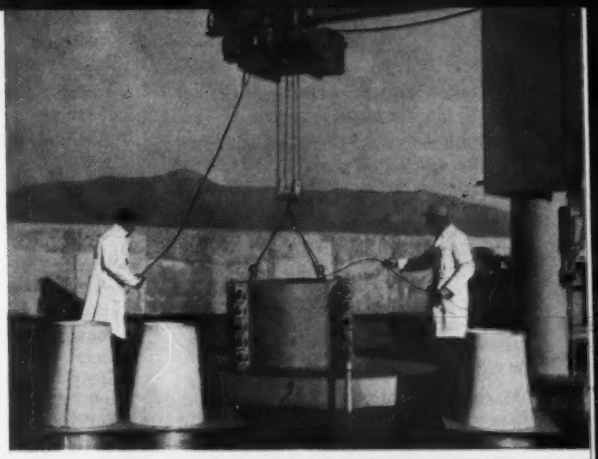
Marquardt/Ogden is now capable of producing space-age hardware in all of its basic configurations—cones, cylinders, rings, parabolic shapes—using the most sophisticated of space-age metals.

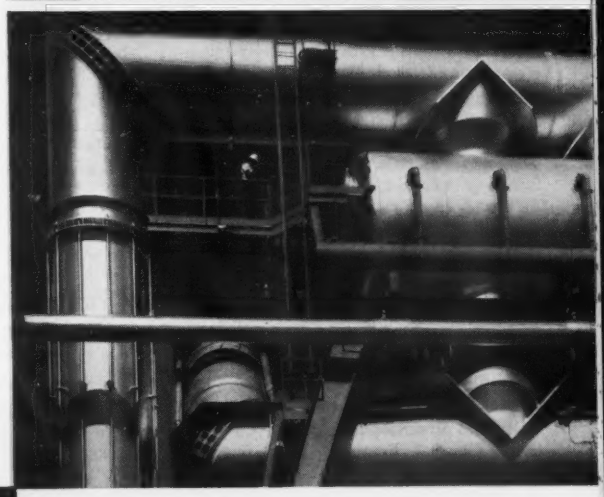
Responsible for Marquardt/Ogden's record are: a creatively cost-conscious management team headed by Mr. D. K. Tasker (pictured left); early application of industry's newest and most advanced production and metal working techniques; a facility cited by *Factory Magazine* as one of America's top ten; and the efforts of the Division's nearly 2,000 men and women workers. All combine to provide Department of Defense and Weapon Systems Managers with a unique capability for the on-time delivery of reliable space-age hardware at minimum cost.

For additional production capability specifics, you are invited to contact: Manager, Customer Relations Department, Ogden Division, The Marquardt Corporation, 1000 West 33rd Street, Ogden, Utah.

Current expansion creates a number of outstanding opportunities for: Product Development, Materials and Process, Manufacturing and Production Test Engineers; and skilled machinists.







TOP. High energy (explosive) forming produces heretofore "impossible to form" shapes—typifies Marquardt/Ogden's continuing quest for optimum materials and processes which advance the art of metal fabrication.

CENTER. Marquardt/Ogden's massive Spin Forge is the most powerful of its type for cold-flow forming of space-age metals. It compliments the Division's new explosive metal forming facility and other specialized equipment.

BOTTOM. USAF-Marquardt Jet Laboratory-Ogden at Little Mountain, some 15 miles West of Ogden, acceptance-tests every production engine system produced by the Division; is capable of simulating flight at speeds in excess of Mach 3, altitudes above 100,000 feet.

OGDEN DIVISION

THE Marquardt CORPORATION

1000 W. 33RD STREET, OGDEN, UTAH

ASTRO ◆ COOPER DEVELOPMENT DIVISION
OGDEN DIVISION ◆ POMONA DIVISION
POWER SYSTEMS GROUP

CORPORATE OFFICES: VAN NUYS, CALIF.

Mr. Sandstrom was formerly Assistant General Manager of the Division.

T. W. Shinafelt (AF) has been appointed to the newly created position of Director of Quality Control and Service for Vought Aeronautics Division of Chance Vought Aircraft, Inc. Mr. Shinafelt was formerly Head of the Division's Service Dept.

Walter J. Spengler (M) Director of Engineering of the Scintilla Division of Bendix Aviation Corp., retired February 1 of this year.

Martin J. Timmons (A), has joined the engineering staff of FluiDyne Engineering Corp., assigned to engineering development and instrumentation projects connected with high altitude simulation chambers, rocket motor test facilities, and shock tubes. Mr. Timmons was formerly a Research Fellow and Research Group Leader in the Aeronautical Engineering Dept. of the University of Minnesota.

George Toumanoff (M) has been appointed Consultant to the Electronic Systems and Techniques Division of Airborne Instruments Lab., a Division of Cutler-Hammer, Inc.

John C. Truman (M), formerly with General Electric Co.'s Small Aircraft Engine Dept., has joined the staff of Knolls Atomic Power Laboratory as a Supervising Engineer on the D1G Project. The Laboratory is operated by General Electric Co. for the Atomic Energy Commission.

J. Paul Walsh (M) has joined C-E-I-R, Inc., as Director of the Space and Weapons Systems Div. Dr. Walsh was formerly Deputy Director of Project Vanguard and Systems Manager for Special Projects at IBM's Federal Systems Division.

IAS News — Corporate Member News

• **Aerojet-General Corp.** has established a new Structural Materials Division, combining the Structural Plastics Division and the Materials Dept.

• **American Bosch Arma Corp.** has made arrangements to purchase Tele-Dynamics, Inc. The firm, which will operate as a division of American Bosch Arma, participates in research and development of airborne transmitting and ground receiving equipment, and recording telemetry electronic equipment.

• **Bendix Aviation Corporation's** missile section has been established as a separate division of the corporation. The newly designated Bendix Mishawaka Division formerly operated as part of the Bendix Products Division.

• **General Dynamics Corp.** has announced the signing of a long-term lease for six floors of 9 Rockefeller Plaza (formerly the Time & Life Building) in New York City. The building will be renamed the General Dynamics Building upon occupancy, scheduled for September 1, 1960, and will serve as the executive headquarters for General Dynamics.

• **General Precision Equipment Corporation's** General Precision Link Division has established a new R & D Laboratory in College Park, Maryland. The primary function of the new facility is the development of electro-mechanical and electronic equipment for missile range instrumentation, missile and space vehicles, ground support, and other related applications.

• **Kollsman Instrument Corp.** has announced the formation of a subsidiary with production and engineering facilities at the Munich Airport in West Germany. The new company's name is Kollsman Luftfahrt Instrumente G.m.b.H.

• **Lear, Inc.** has announced formation of a Service Division to serve all manufacturing divisions. The new division will provide unified service to Lear customers in all military, commercial, and industrial products.

• **Lockheed Aircraft Corp.** has announced plans to acquire 50 per cent interest in the Grand Central Rocket Co. Purpose of the acquisition is to round out Lockheed's missile, satellite, and spacecraft capabilities.

• **Marquardt Corp.** has established a new Facilities Engineering Division. Function of the new division is to provide capabilities in the architect and engineering field to pursue facility and associated design projects for governmental and commercial installations.

• **The Meletron Corp.** has purchased the William C. Gillette Building in Los Angeles to house the company's manufacturing operations.

• **Mid-Continent Manufacturing, Inc.** has announced that its name has been changed to **Automation Industries, Inc.** The company is engaged in the fields of ultrasonics, magnetics, production of missile parts and components, and industrial equipment leasing. Construction of a new plant facility in Torrance, Calif. is now underway, with occupancy as the company's headquarters scheduled for around June 1.

• **Thompson Ramo Wooldridge Inc.** has announced plans to move its Tapco Group West Coast production from Bell and Long Beach, Calif., to Cleveland, Ohio. The reason given for the move was that "higher volume production capacity in similar product lines is available in Cleveland."

• **United Aircraft Corp.'s** wholly-owned subsidiary, United Research Corp. of Menlo Park, has changed its name to **United Technology Corp.** The name change reflects more definitively the work and scope of activities the company is undertaking.

T. F. Walkowicz (AF), a member of the Laurance S. Rockefeller staff, Rockefeller Brothers, Inc., has been named to the Board of Directors of Cornell Aeronautical Laboratory, Inc.

Necrology

Harry W. Bartz (A)
December 15, 1959, Tonawanda, N.Y.

Harry N. Blosser (M)
October 27, 1959, Ft. Worth, Tex.

Sterling P. Fergusson (AF)
November 26, 1959, Milton, Mass.

William Wager Medlin (M)
January 24, 1960, Huntsville, Ala.

Meet the Staff

An Aero/Space Engineering feature on personnel of the IAS

Leonard Rosenberg— *Printer*

Indispensable to the quality and unending variety of printed matter produced by the Institute's National Headquarters Printing Department are the abilities of Leonard Rosenberg. He is assistant to Walter Wills, head of the Department, who was the subject of this feature in August, 1958.

Talents siphoned from Lenny's printing skills have made themselves evident in several IAS print shop productions recently—the Wright Brothers Lecture booklet (design and layout by Rosenberg), the IAS Charter Certificate (design by Rosenberg), and the new IAS Film Library brochure (redesigned by Rosenberg).

Lenny joined the IAS staff in November of 1943. He is twice a war veteran (World War II and Korea, serving in the latter action as Army Signal Corps Instructor). He and Mrs. Rosenberg, who are the parents of a daughter, make their home in Kew Gardens, Long Island.

IAS News — IAS Sections

Chicago Section

Wind Tunnel Demonstration

Charles E. Eves, Staff Engineer in charge of Cook Research Laboratory's wind tunnel, presented a general discussion on the tunnel's construction at the January 13 dinner meeting in preparation for a visit to the facility. Mr. Eves' presentation was illustrated with a number of slides.

At Cook Research Laboratory, the wind tunnel was further explained and demonstrated for the group. The tunnel is a continuous flow, open circuit atmospheric induction type with either fixed or variable flow nozzles. The test sections are two-dimensional with airflow available by adjustment of two, J-47 turbojet engines. The tunnel has the advantages of general utility by adapting to a selection of speed ranges in a very short time. Supersonic Mach numbers can be varied continuously from the low supersonic to a Mach number of approximately 2.7 with a 24 in. by 22 in. variable asymmetric nozzle.

MILES J. MRAZ, *Secretary*

Cleveland-Akron Section

RAMP Early Warning System

A tour of the new Engineering and Science Hall of Fenn College in Cleveland opened the January 12 meeting, which featured a dinner on the college's campus and an address by **Harry Letaw, Jr.,** Manager, Systems Applications, Research Division Raytheon Co.

Stating that studies made by the Raytheon Co. lead them to believe in the feasibility of the Raytheon Airborne Microwave Platform system (RAMP) as an Early Warning System, Dr. Letaw presented a general discussion on the project. The proposal involves the use of high-altitude helicopters intended to be used as radar platforms. The unique feature is a beamed microwave power source developed by Raytheon which makes it possible to supply power to the helicopters from ground installations. Both military and civilian applications were included as possibilities.

R. K. CHAMBERLAIN, *Secretary*

Hampton Roads Section

Military Mobility; Astronaut Training

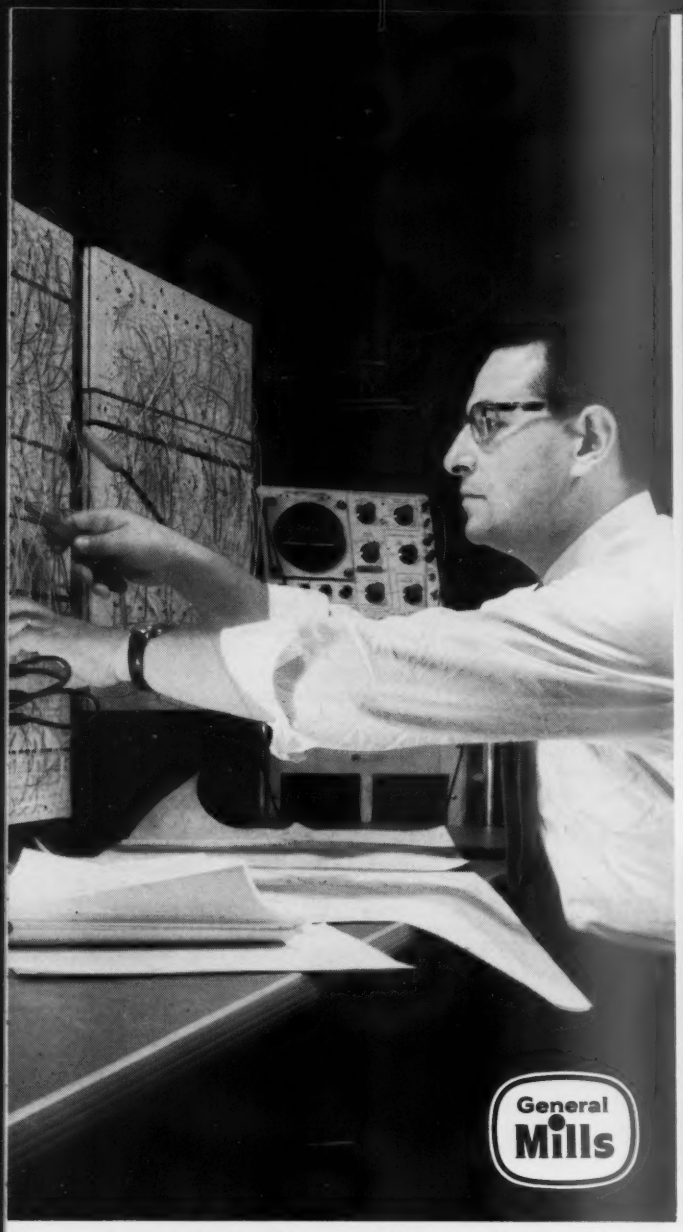
The stalemate that is developing in military missile strength is such that each nation will have sufficient strength to serve as a deterrent to the other's attacks, and small wars may become useful to a potential enemy as a means for achieving supremacy. The advantage is then with the side having the most flexible striking force. This was the basis of the argument explored before the January 12 meeting by **Brig. Gen. Benjamin S. Kelsey,** USAF (Ret.), Technical Associate of Booz Allen Applied Research, Inc.'s Washington Operations.

Advocating a truly mobile striking force capable of moving rapidly to any place in the world, General Kelsey pointed out that an essential requirement of a striking force is an aircraft which has great operational flexibility. The aircraft should be capable of trading range, load, speed, and take-off and landing distance between wide limits. He felt that the VTOL/STOL type machine offered great promise of operational flexibility. The difficulty of determining the design trade-off's in this relatively new and unusual type machine was discussed. General Kelsey indicated that the state of the art would permit the design of such machines and strongly recommended that their development be pursued vigorously.

The December 21 dinner meeting featured a discussion on **"Highlights of Astronaut Training"** by **Lt. Robert B. Voas,** USN Medical Corps, Astronauts and Training Group Space Task Group. Lt. Voas is presently on assignment to NASA's Project Mercury.

Opening his presentation with a film, "Status of Project Mercury, October

Among those present at the December 9 meeting of the Indianapolis Section were *(left to right)* H. W. Welsh, Vice-Chairman; W. Emmich, Program Chairman; Jack Real, guest speaker; H. D. Wilsted, Chairman; and F. J. Quetglas, a representative from the Air Traffic Control Service of Spain.



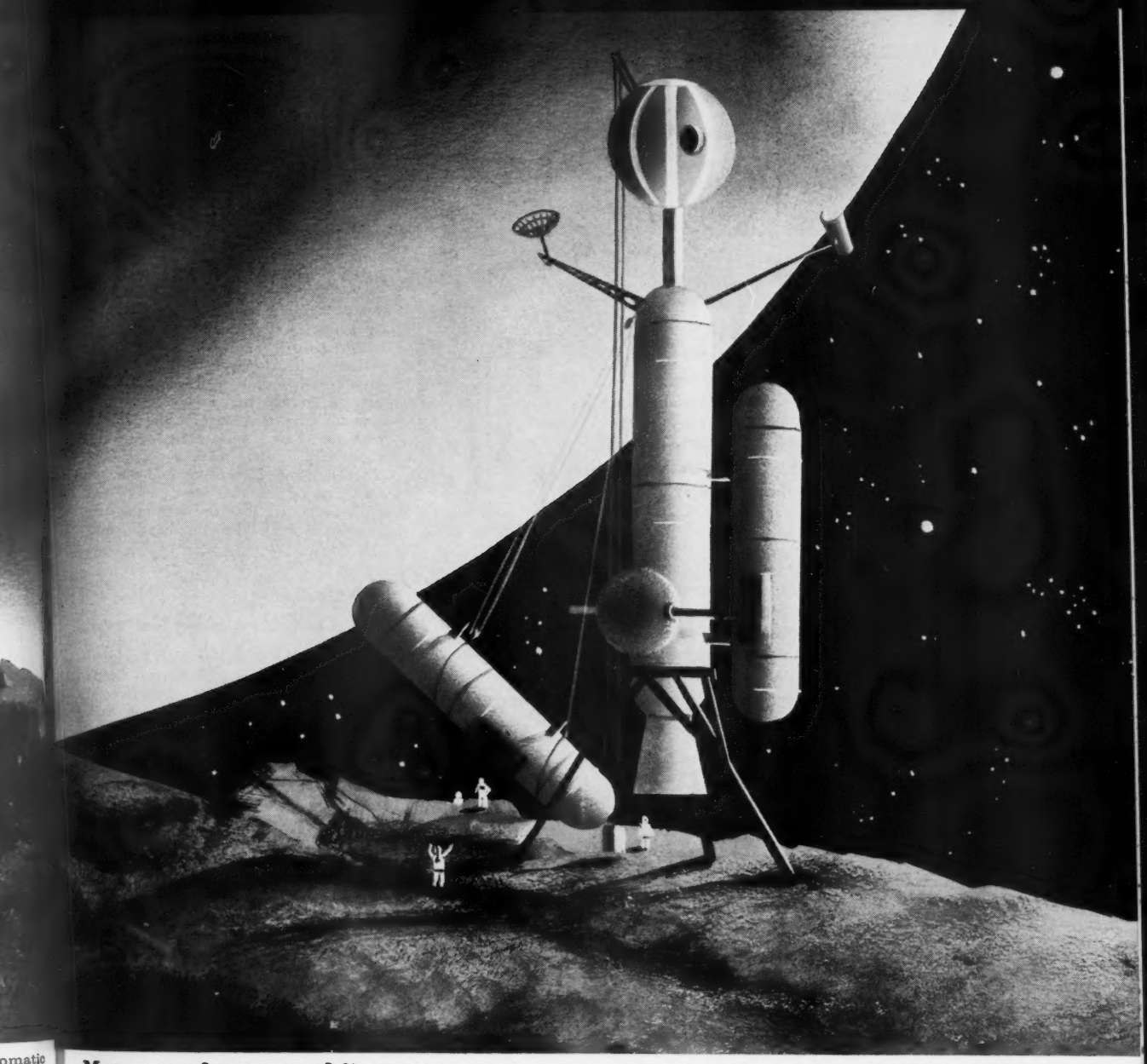
Here is Francis Alterman, Manager of General Mills Digital Computer Laboratory, checking one of our newest computers which he helped design. General Mills computers, both analog and digital, are being used in missile guidance, bombing and navigation systems, automatic surveying and in industrial control. In future space travel, computers will help control navigational systems of space vehicles and will process data gathered in outer space.

General Mills engineers work today

General Mills has been producing computers for nearly 20 years. Exciting new concepts in high speed magnetic tape units, ultra-high precision analog to digital converters and optical keyboards are examples of continuous developments in our over-all computer program. We work to improve reliability, increase speed, cut cost.

Our research activities cover broad areas in physics, chemistry, mechanics, electronics and mathematics. Some of the studies representative of these activities are: ions in vacuum, deuterium sputtering, dust erosion, magnetic materials, stress measurements, surface friction and phenomena, trajectory data and infrared surveillance.

In our engineering department, current projects include: specialized inflatable vehicles and structures, airborne early warning systems, micro wave radar test equipment,



Mars seen from one of its moons . . . illustration from book written for General Mills by Willy Ley.

to help you explore space tomorrow

antennas and pedestals, infrared and optics, inertial guidance and navigation, digital computers—and many other activities.

Our entire manufacturing department is geared to produce systems, sub-systems and assemblies to the most stringent military requirements. Our people have a wealth of experience in complex military projects.

Write for free booklets: (1) Complete research, engineering and manufacturing capabilities of the Mechanical Division (2) New booklet on General Mills computers.

MECHANICAL DIVISION

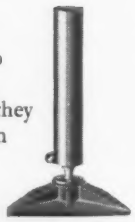
1620 Central Avenue, Minneapolis 13, Minnesota

To wider worlds—through Intensive Research • Creative Engineering • Precision Manufacturing

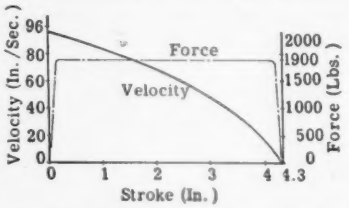
General Mills

How to drop 2750 lbs. 12 inches without damaging sensitive electronic equipment

You can do it with unique *Droppable Load Buffers* by Houdaille. Designed to protect portable search radar during combat-condition helicopter drops, they combine maximum shock absorption with leveling adjustments.



This hydraulic buffer is just one of the Houdaille designs that can be used or adapted to solve your own damping requirements. Houdaille buffers now in production provide resisting forces from 100 to 125,000 lbs.—with strokes from 1 to 9 inches. Typical applications include radar antenna limit stops, navigational control systems, and missile handling equipment.



Graph shows constant damping force of Houdaille Droppable Load Buffer. Infinite variations in pattern of damping orifices allow great flexibility in meeting your damping needs.

HOUDAILLE QUALITY PRODUCTS

Houdaille Industries, inc.

Buffalo Hydraulics Division

542 E. Delavan Ave., Buffalo 11, N. Y.

. . . Specialists in hydraulic damping and vibration control

Send this coupon for engineering bulletins giving performance curves and other data.

Name

Address

City *Zone* *State*

1959," Lt. Voas illustrated the general design and operational concepts of the project. He then reviewed the criteria which were established for the selection of the astronauts and described some of the training which they are undergoing. Their activities fall into the following categories: (a) training in astronautics and space biology, (b) participation in Mercury development plan, (c) conditioning for space flight, (d) training for operation of Mercury Vehicle, (e) familiarization with ground operations, (f) continued flight training. The use of such simulators as the centrifuge, flight simulator, and devices which duplicate the heating environment which the astronaut will undergo in the actual Mercury flight form an important part of the training program. Each man is trained to become a specialist in some particular field such as pressure suits, instruments and controls, etc., relating to the Mercury system. Lt. Voas stated that the astronauts are progressing well in their training program.

LAURENCE K. LOFTIN, JR., *Secretary*

Indianapolis Section

Engineering Flight Test

Jack Real, Division Engineer, Engineering Flight Test, Lockheed Aircraft Corp., discussed his company's departmental test structure and functions of each department in relation to the planned test program at the December 9 dinner meeting. Mr. Real's presentation, **"Engineering Flight Test,"** included a summary of the Electra and F-104 test programs with an illustrative film of the tests and evaluations in the program.

NORMAN M. JONES, *Secretary*

Kansas City Section

Impact of Jet Transports

The January 25th meeting opened with a tour of Trans World Airlines' Flight Training Facility. The speaker at the dinner following the tour was **Don Finlay,** Chief of Preliminary Design, Transport Division, Boeing Airplane Co., who discussed **"The Impact of Jet Transport on the World's Travel and Shipping Habits."** Mr. Finlay related the statistics and theories which form the basis for predictions of coming events in the transport field.

The past year, 1959, provided the first real insight into the effect of jet transport travel on our economy and travel habits. Many new speed records have been set, and the utility of the jets has proved to have high load and reliability factors. However, in comparison to piston-powered aircraft, statistics are meager and predictions of the future of the jet transport do not lend themselves to strict extrapolation of available data.

Mr. Finlay stated that great increases in passenger travel are due to increases in speed and not necessarily increases in comfort. No firm prediction of speed with time was made; however, it was stated that the supersonic transport is with us and optimistically it can be done without the military but will probably take longer to accomplish. Mach 2.25

Flames swept across the open plains as the Mongol hordes ran in terror from the "arrows of flying fire". When the smoke had cleared the Chinese had won the battle of Pienking with the first rocket.

Missiles have become greatly more sophisticated since this crude unguided arrow was propelled by gunpowder packed in an open-ended bamboo tube. Today, as a vital part of one of the world's largest electronics companies, Raytheon's Missile Systems Division is making significant contributions to the art of missilry. The exciting new Pin Cushion Project for selective missile identification, the constantly advancing Navy's air-to-air SPARROW III and Army's HAWK are examples of their outstanding creative work.

We are seeking highly creative people to maintain Raytheon's leadership in this challenging field. For these people, Raytheon's Missile Systems Division creates a climate for talent — perhaps *your* talent.

MISSILE: 13th CENTURY

SPECIFICATION ENGINEERS . . . will prepare design specifications, clearly defining contractual obligations and responsibilities. Close contact with design and development personnel to provide technical information necessary for specifications. B.S.E.E. or equivalent desirable, with strong electronic experience in radar, or missile systems.

Please reply to Mr. Walter N. Wells, Professional Personnel, Missile Systems Division, Raytheon Company, 520 Winter Street, Waltham, Massachusetts.

RAYTHEON MISSILE SYSTEMS DIVISION

. . . creates a climate for talent.

appears to be the optimum jet transport speed.

F. A. ROSENTHAL, *Secretary*

New Mexico Section

Booster Recovery

Paul T. Shipps, Senior Designer, Preliminary Design, Convair Division of General Dynamics Corp., presented a paper entitled, **"Methods and Economics of Recovering Boosters for Orbital Vehicles,"** before the January 28 dinner meeting. Mr. Shipps had presented this paper at the IAS 28th Annual Meeting on January 26.

Mr. Shipps stated that studies conducted at Convair into the feasibility of recovering orbital vehicle boosters for reuse were based on placing at least 25,000 lbs. into orbit. These studies indicated that a two-stage vehicle was most practical, the first stage being the recoverable portion. Comparisons were made for four types of systems which included built up rocket boosters, optimized rocket boosters, semi-recoverable boosters, and highly recoverable boosters. Each system was described and illustrated by slides. The first two, built up and optimized boosters, were considered to be non-recoverable while the semi-recoverable type incorporated a parachute assembly. The economics of each system were calculated for a few firings up to several hundred based on the premise that the first stage booster could be recovered for the latter two types. These became economically feasible after approximately two hundred reuses. It was concluded that it was desirable to incorporate in the highly recoverable booster air-breathing engines, wings for low altitude lift and control, and structural strength for landings. Also, it was quite advantageous to have the booster recovered at the initial launch site. Additional flexibility could be gained by incorporating into the first-stage recoverable booster system a human pilot who would be able to exercise some degree of judgment and control.

LT. COL. L. T. BOATWRIGHT, JR., *Secretary*

Omaha Section

Aircraft Nuclear Propulsion

A. A. Hafer, Manager, Applications Research and Planning, Aircraft Nuclear Propulsion Department of the General Electric Co., addressed the section's January luncheon meeting. Mr. Hafer's topic was, **"Mission Considerations for Nuclear Propulsion of Aircraft and Missiles."**

After a brief review of the basic principles of aircraft nuclear propulsion, the unique features of this new form of propulsion were discussed from the standpoint of its effect on systems design and mission considerations. The interrelations of such features as shielding, maintenance, ground handling, and endurance were considered as they affect aircraft and missile design and mission considerations. Mr. Hafer told of the work of General Electric in ANP: The X-211 direct cycle nuclear turbojet engine which ran on chemical fuel in 1958, GE facilities at the Idaho test site for "hot" tests, and the test device which utilizes two J-47's harnessed to a reactor. A few of the reasons for using the direct cycle as opposed to the indirect cycle for nuclear turbojet applications were explained. First, the handling of the reactor assembly during maintenance is made easier because it is a complete unit and would require a minimum number of control disconnects whereas the indirect cycle using a liquid metal for the heat transfer fluid would not lend itself to easy removal because of the extensive plumbing connections and the problems associated with draining the heat transfer fluid. Also, the indirect cycle presents an extreme design problem in providing plumbing for the heat transfer fluid. One disadvantage of the direct cycle engine involves the problem of shielding which may restrict engine location in an airframe design.

In conclusion, Mr. Hafer discussed Russian activities in the field of ANP. He stated that examination of their literature revealed no disputes, and he showed a few slides of Russian drawings of ANP aircraft. They were all characterized by a very long fuselage with engines mounted in the rear. Mr. Hafer recommended further investigation of Russian ANP by securing copies of the Congressional Testimony on the July 1959 ANP Hearings. This document includes translations of Russian ANP papers in the appendix.

MICHAEL J. MCALISTER, *Secretary*

Seattle Section

Wright Brothers Lecture; Considerations for Hypersonic Flight

Dr. Alexander H. Flax, Chief Scientist, USAF, made the sixth presentation of the 23rd Wright Brothers Lecture, **"High Temperatures in Hypersonic Flow—Physical Principles and Experimental Techniques,"** before a special section meeting on January 19.

The regular section meeting on January 14 heard **Dr. Alfred J. Eggers** discuss **"Some Considerations of Aircraft Configurations Suitable for Long Range Hypersonic Flight."** Dr. Eggers is Chief of the Hypersonic Vehicles and Environment Division of Ames Research Center, NASA.

Dr. Eggers opened with a brief history of hypersonic flight stating that the original concept of a hypersonic glider was developed nearly 25 years ago. Serious work at NACA (now NASA) was begun after he and Dr. Allan prepared a short study indicating that the glider looked promising when compared to ballistic or supersonic airplane systems.

The basic properties of hypersonic gliders were then reviewed using the fundamental range equation. The effect of vehicle lift-to-drag ratio on boost velocity requirements and mass ratio was shown to be small for ranges approaching the circumference of the earth. Also, the heat transferred per unit area was higher for higher lift-to-drag ratios when the range was more than 1/4 of the earth's circumference. Dr. Eggers then showed the development of two possible hypersonic configurations—one of high L/D and the other of low L/D. Considerations of favorable interference lead to a conical body with a high wing drooped about 30° at the tips for the high L/D configuration. Tests at M=5 have verified the advantages of this configuration, but extension to M=20 by the Hypersonic Similarity Law resulted in shapes impractically slender.

The low L/D configuration shown was a blunt conical body with a small high wing giving an L/D of 0.8–0.9. This vehicle gave up to ±750 mi. maneuvering capability without large losses in range and had an equilibrium temperature of 3000°R using a radiation heat shield. This configuration showed no marked variations in aerodynamic characteristics throughout the Mach number range that has been tested.

In summary, Dr. Eggers pointed out a corridor on the speed-range map within which hypersonic vehicles could be built. The top (high speed-low L/D) side of the corridor was limited by vehicle launch weight and the lower (low speed-high L/D) side was limited by total heat transferred.

JOHN K. WIMPRESS, *Secretary*

Tullahoma Section

Life on the Moon

"Biological Protective Environments on the Moon" was the subject of a presentation by **Milo Hnilicka** of the National Research Corp. at the January 20 dinner meeting. Dr. Hnilicka discussed many of the problems associated with establishing and sustaining a colony on the moon surface. His work was the basis for an artist's sketch of a moon village which appeared in a recent issue of Life magazine.

WILLIAM L. CHEW, JR., *Secretary*

Tulsa Section

Annual Family Night

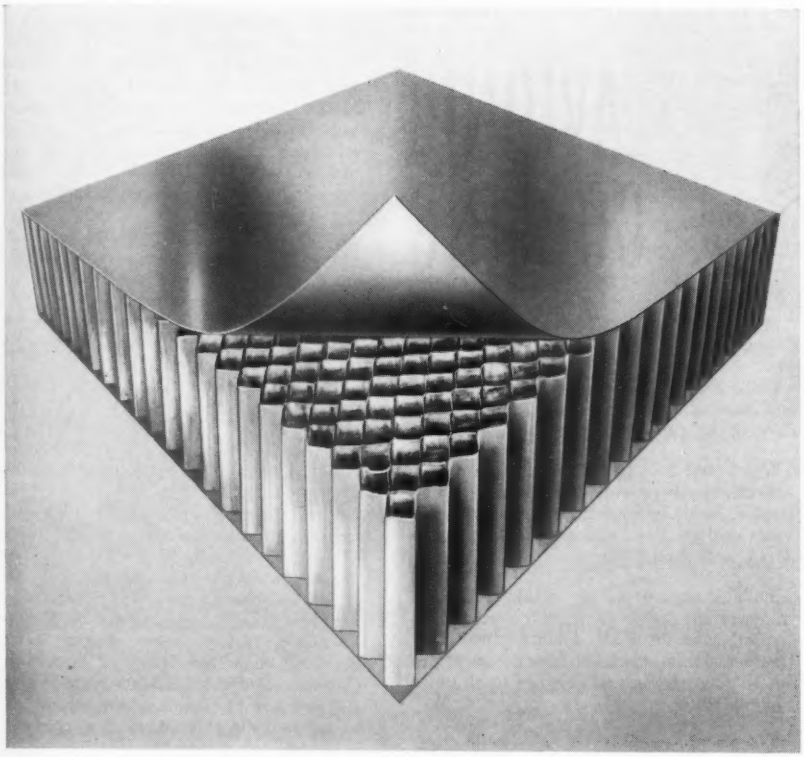
Friday, January 15, was the date for annual family night, which included a cafeteria dinner followed by a movie program.

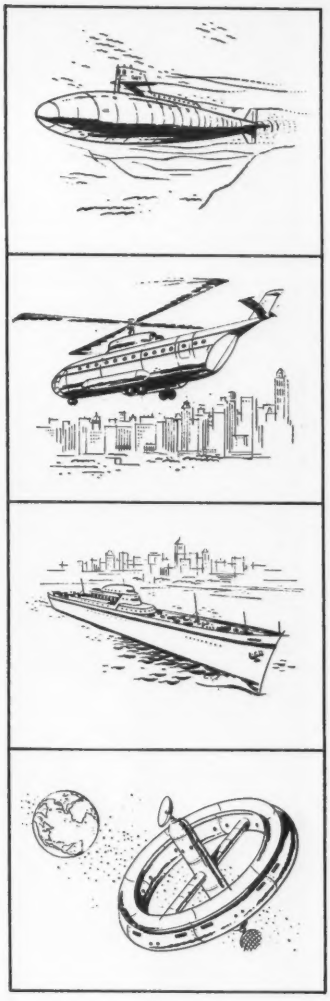
The first feature, "Unfinished Rainbows," told the interesting and challenging story of aluminum. While we consider aluminum to be an every day commodity, at one time it was more precious than gold. Its transformation into one of the world's most useful materials has offered a challenge to man. The problems of introducing aluminum for use by various manufacturers were many and difficult. The film also told of the challenge to youth in things yet undiscovered.

"Thunderbird" told the story of the U. S. Air Force acrobatic team, showing maneuvers from the ground, air, and from the performing planes. Part of the film's narration employed actual radio conversation between the pilots.

The third film, "The Big Reach," told the fascinating story behind the U. S. Air Force Lunar Probe, including the processes and procedures required

NEW STRUCTURAL MATERIAL FOR INDUSTRY!





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New fabrication and manufacturing techniques developed by Rohr show great promise of a cost breakthrough for brazed stainless steel honeycomb sandwich structures. There are countless possible applications throughout industry . . . perhaps in yours.

This incredible material, widely used in the aerospace industry, is earmarked for far broader applications as its unique characteristics become better known to designers.

The "sandwich of steel" is able to withstand great temperatures for prolonged periods — six times that of aluminum, for example. It can cope with sonic and acoustical environments impossible for conventional structures.

Brazed honeycomb sandwich panels offer outstanding insulation qualities, and their structural characteristics are extremely attractive when the problem is to increase strength while substantially reducing weight.

Rohr, a pioneer in the development of brazed honeycomb, has evolved new methods which permit the fabrication of these structures in virtually any size, quantity or configuration, including flat, wedge, curved, and compound curved panels.

For less demanding applications, principally where the problem is one of strength/weight ratio, Rohr honeycomb panels can be fabricated more economically from other materials and bonded adhesively rather than by brazing.

Perhaps you can put this dramatic new material to work in your business. A new brochure, explaining the characteristics of honeycomb paneling in detail, is available upon request. Write Mr. B. R. Alsobrook, Manager, Brazed Stainless Steel Products, Rohr Aircraft Corp., P.O. Box 878, Chula Vista, California.

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Eastern

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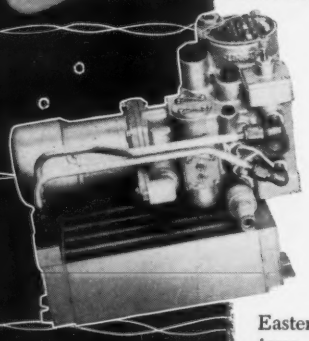


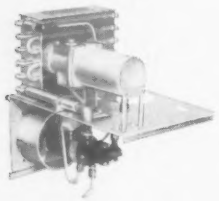
Eastern cooling packs for electronic subsystems extend operating ranges to altitudes where air cooling becomes ineffective. 'Black box' designs can be more compact—reliable even at five times the speed of sound.

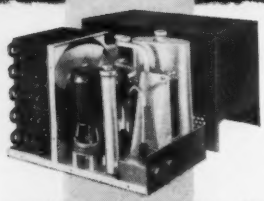
These liquid cooling systems are completely self-contained—provide such components as pumps, heat exchangers, air impellers, reservoir, coolant flow and temperature interlocks and similar parts.

Cooling capacities of existing systems range from 1,000 to 22,000 watts dissipation rates. Eastern cooling packs take ambient temperatures from −55°C to +55°C in stride, and perform to altitudes of 60,000 ft.

Extensive experience in missile applications has enabled Eastern to develop systems unusually compact and light as well as highly reliable. At the same time, Eastern is able to provide at minimum cost equipment engineered to a specific need by using missile-proved components designed to your system configuration.

Turn to Eastern for space-, weight-, and cost-saving solutions to your hottest cooling problem. Write for New BULLETIN 360.





liquid cooling units for 50 to 50,000 watts dissipation

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before a rocket can be fired. Difficulties encountered and results obtained from each rocket fired were shown.

P. C. JOHNSON, *Recording Secretary*

Washington Section

Turbine Powered Transports

Frank W. Kolk, Director of Equipment Research for American Airlines, addressed the November meeting on the subject of **"Turbine Powered Transports—Operational Experience Including Comparison with Original Estimates."** Prior to Mr. Kolk's discussion, a number of guests were introduced, including Dr. Shizuo Kikuhara of Shin Meiwa, Japan, who was visiting the United States under sponsorship of the Navy's Bureau of Aeronautics to discuss aircraft hydrodynamic developments. Dr. Kikuhara spoke briefly on current Japanese aircraft programs, noting contributions by this country to Japanese aviation activities by bringing their technical knowledge up to date when design work resumed in Japan in 1954.

Honorary Meeting Chairman William Littlewood, 1959 IAS President, then introduced the speaker for the evening. Subtitling his subject "The Non-Scientific Approach to Jet Planning," Mr. Kolk opened by noting that the advent of the jet transport brought about the most radical change in equipment and operating philosophy experienced by the scheduled airline industry. The change can be considered revolutionary in comparison with previous evolutionary changes. This discussion reviews some of the major decisions made by American Airlines in planning the introduction of the Boeing 707 and how the assumptions which had to be made in this planning worked out in practice.

In determining the desired configuration for the American Airline 707's, the approach of setting the number of passengers and/or size of cargo on given routes was discarded. With an early decision to use Pratt & Whitney JT3C (5-57) engines and a fixed basic wing, the objective was to adjust the overall design to give the greatest system flexibility and efficiency. One necessary mission was defined: operating non-stop from New York to San Francisco with a full passenger load, this being the longest and most adverse route on which the aircraft were to be operated. This approach necessitated the estimation of the environment for this flight, the size of the airplane then being adjusted to perform this flight in the estimated environment. Fuselage length was a variable—if very long, weight limited payload, if very short, capacity payload was reduced for all other less critical flights. As a result of these studies the basic 707 originally specified was lengthened by 120 in. to produce the optimum design on this basis. The environment estimation included comparisons of calculated take-off distances for various gross weight and temperature conditions with what were felt to be reasonable runway lengths. Based on their current DC-7 and British

(*Continued on page 109*)

Janitrol Reports

on aircraft and missile components

Cooling with Boiling Water

This Janitrol "water boiler" heat exchanger serves as an air conditioner for hot pilots at supersonic speeds. High temperature air passes through unique tubular structure made of extremely thin plates, and water on the primary side of the exchanger boils. Sufficient heat is extracted to enable mechanical cooling equipment to complete the job. Long experience with high temperature alloys

in foil-thin sheets have enabled Janitrol to achieve significant weight savings as well as excellent heat transfer efficiency, simple manifolding, and design freedom of value to engineers trying to shoe horn the components into odd spaces.

Million BTU per Hour

If you like your heat wave in small packages – to heat buildings or vehicles for personnel comfort, to process fluids, to prevent freezing in transit or storage –here's a liquid heater of modest dimensions that puts out up to a million Btu per hour, can operate on almost any fuel (gas, diesel fuel, JP-4 and LP gas) and starts reliably down to – 65°F. Output is variable: it will maintain liquid at any specified temperature (within reason). Other Janitrol heaters of less impressive capacity are serving reliably on emergency fire-fighting vehicles to keep fluids fluid at all times all year round.

Minus nothing–Plus very little

The tolerances specified in Janitrol pneumatic control valves and regulators are so tight as to call for considerable artistry in their manufacture. To provide high reliability, the valve must not deliver less than specified performance; yet the designer must observe all weight restrictions and safety factors. And because air is such a versatile servant in advanced aircraft – for canopy seal, fuel transfer, blowers, coolers, actuators, and what have you–Janitrol valves and regulators are finding new and exciting applications every day.

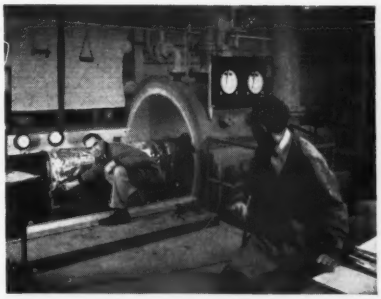
Bracelets for bleed air lines

The Janitrol couplings which tie together the vital lines for high pressure air in aircraft and missiles are far from decorative. Yet they must possess jewel-like perfection.

They must stay tight under pressures up to 600 psi, temperatures up to 750°F. In addition to withstanding heavy vibration and bending loads, they must permit disconnects and pressure-tight reassembly repeatedly, reliably.

In Janitrol Dubl-lock couplings, an extra measure of safety is included: a tang lock will hold even if the bolt should fail under overloads or over torquing. You can get Janitrol standard or Dubl-lock couplings in stainless steel or titanium, in sizes up to 7″ diameter, and specials up to 36″ in diameter.

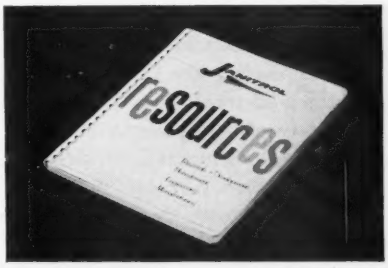
Janitrol's unique experience in welding and fabricating high temperature alloys to extremely tight physical and dimensional specifications has contributed much to the reliability of pneumatic systems in aircraft.



Birth of a Notion

A good measure of Janitrol confidence in the future of the aero-space age is its new research, development, and manufacturing facility in Columbus, which includes among other things one of the industry's best privately owned high altitude chambers (shown above). The six-foot diameter, twenty-foot long chamber simulates altitudes up to 100,000 feet plus, temperatures down to – 80°F.

These are just a few examples of Janitrol's unique capabilities in building true reliability into heat exchangers, couplings, pneumatic controls, and related hardware – and *undertaking major research and development projects* as well.



We invite you to write for "Janitrol Resources," a comprehensive illustrated brochure on Janitrol capabilities. Janitrol Aircraft, a division of Midland-Ross Corporation, 4200 Surface Road, Columbus 4, Ohio, BRoadway 6-3561.

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EDITORIAL

A Policy Statement . . .

. . . submitted by the Institute of the Aeronautical Sciences to the Committee on Science and Astronautics of the House of Representatives on February 23, 1960.

We were recently in receipt of a letter addressed to IAS President Putt from the House of Representatives Committee on Science and Astronautics from which the following is quoted: "The Chairman has also decided to set aside one day to hear from certain key professional societies and similar groups which speak with knowledge and experience on matters related to space. Accordingly [you are invited] to prepare a statement, preferably the official views of your organization or its directors, otherwise your personal views if there is not agreement from the group. . . . We think it is time again to hear what should constitute our goals in space research, development and operations; the degree to which we are ready to meet these challenges; and any other observations which would be helpful to Congress and the public." February 23 was designated as the day for hearing from the societies.

In order to determine what should be done in response to this invitation, General Putt called a meeting of available members of the IAS Executive Committee and Staff at the Cosmos Club in Washington on February 15. At this meeting it was agreed that Dr. H. Guyford Stever of M.I.T., a member of the Council, should represent the IAS before the Committee and that the IAS statement, based on discussions at the meeting, be drawn up jointly by Dr. Stever and the Director. The final statement was referred back to the Executive Committee for approval before presentation. It appears below.

We consider it a pleasure and a privilege to appear before your Committee in response to your Chairman's invitation. We recognize the importance of the work that your Committee and the other Committees of the Congress are doing in their effort to maintain the position of scientific and technological leadership which the country has long enjoyed. It is vital that we retain this leadership as a guarantee of our national security and of our future economic welfare.

We appreciate the Committee's inclusion of certain scientific and technical societies on its list of witnesses in the area of aerospace technology. Just as the Congress is the open forum in which economic, military, and political matters concerning the welfare of the United States are debated, so our scientific societies make up the forum in which scientists and engineers expose new theories and advanced ideas for debate and discussion in the presence of their colleagues. In this way science and engineering are advanced, and the body of basic scientific knowledge grows.

As a scientific society dedicated to the advancement of the art and science of aerospace technology, the Institute of the Aeronautical Sciences engages in two principal forms of activity:

(a) It facilitates through its meetings and its publications the rapid interchange of scientific and technical information among the 15,000 scientists, engineers, educators, and industrialists which comprise its graded membership.

(b) It encourages qualified students in our schools and universities to prepare themselves for positions of leadership in the aerospace sciences. It has some 5,000 students enrolled in Branches at some 80 universities in the country.

Institute meetings are organized at National, Regional, and Sectional levels. Subjects range over the whole spectrum of matters relating to aerospace science and technology. In any calendar year (not counting meetings held by Student Branches), their number averages one per working day. Nearly 600 papers are prepared and presented at such meetings yearly, many of which are published in IAS journals or periodicals.

Supplementing the regular meetings, frequent briefings and inspection trips to Government R&D and testing facilities are organized. Most of these are classified, and all are carefully controlled by the sponsoring agency for security. Such field trips offer invaluable opportunity for Government and industry personnel to exchange ideas on an informal basis.

The IAS Student Program includes periodic Branch Meetings, as well as Annual Regional Conferences. Vocational guidance material for high school students is compiled and distributed on a country-wide basis.

To service the professional needs of its membership the Institute maintains two technical libraries, one in New York and one in Los Angeles. In addition to making available up-to-date books, periodicals and reports, these libraries produce voluminous monthly abstracts of pertinent literature in the aerospace sciences from all sources, including the U.S.S.R. These appear monthly in IAS publications.

The Institute is also the custodian of a number of annual awards to honor outstanding contributions by individuals to progress in the aerospace sciences. The most recent—and of particular interest to your Committee—is The Hill Space Transportation Award.

The Institute's only mandate under its Charter is to advance the aerospace sciences. Its sole objective is to raise the level of the country's scientific and technical competence in the aerospace sciences so that there will always be an adequate number of qualified professional people available to maintain our technological leadership.

With the above in mind, it is clear that we cannot come before your Committee today to speak *as an organization* as to what should constitute specific goals in space research, development, and operations. These are questions of national policy which must be determined by the Executive and the Legislative branches of Government. The Defense Department must set the requirements for national security and conduct the necessary military space programs. Under the National Aeronautics and Space Act of 1958, the National Aeronautics and Space Agency has the responsibility to plan for and to conduct the nonmilitary aspects of space exploration. The Congress, after considering national policy objectives and the state of the national economy, must decide on desirable rates of development and optimum levels of operations for the space program.

Individually, many officers and members of this Institute cooperate with and assist many agencies of Government in evaluating specific proposals and in determining properly balanced programs in aeronautics and in space technology. As individuals, many of them have strong personal views on such subjects. Some of them have undoubtedly testified before your Committee. It would be quite presumptuous for us as an organization, however, to appear before you to recommend this or that specific program, or to suggest that more or less money be allocated to one or to the other of the Armed Services in support of one weapons system over another. We are not equipped to do so. Such things are outside the scope of our Charter.

As an organization, however, we believe strongly in the necessity and in the urgency of extending the boundaries of human knowledge of the universe in which we live. New techniques developed in the past decade have opened up possibilities for exploration and for exploitation of space at speeds and at altitudes ranging from zero out to infinity. It is essential that we take full advantage of these capabilities both for the betterment of our people and for the security of our country.

At the same time we must not allow ourselves to be completely distracted by these glamorous new capabilities. Few people now living will experience space travel or participate personally in space exploration. For the foreseeable future, by far the bulk of human travel, and, in fact, the major theaters of military conflict, will be restricted to the surface of the Earth, or to the thin shell of atmospheric air which envelopes it. Every space vehicle must transit the atmosphere on its outward track, and must cope with complex re-entry problems on its return. We must, therefore, not overlook or neglect the aeronautical aspects of the aerospace sciences. Many difficult and complicated problems yet remain to be solved before we can attain complete mastery of the Ocean of Air in which we all are living. Our aerospace programs for national welfare and for national security must be properly balanced, if they are to be effective.

Activities such as ours contribute directly to the ability of the country to meet such challenges by improving the technological capabilities of our scientists and engineers. In recent years there has been a marked shift in the interests and activities of our members from air-breathing aircraft and their components and research problems, to ballistic missiles, space vehicles, and the associated space technology. This did not start at the launching of Sputnik I, but was already under way by the end of World War II. In the following decade, although space vehicles were seldom mentioned as such, many of the papers presented in Institute meetings dealt with scientific subjects on which present technology is based.

Leading aerospace engineering, scientific, and industrial people in this country are members of this Institute. They are graduates of our great universities and engineering schools. Many of them have had up to half a century of background and experience in their profession. We believe that membership in the Institute has added to their capabilities.

The U.S. has a responsibility for world leadership. Leadership is compounded of many factors, and any nation aspiring for leadership must be a leader in all major factors involved. The past decade has seen science and technology emerge as a dominant factor in world affairs. Military, political, economic, and social decisions cannot be made without consideration of the influence of science and technology in such areas. Not only is technology the foundation of our national prosperity but also of our military strength. It is essential, therefore, that we adopt every possible means to expand and to improve our human resources in the scientific and engineering fields.

The technical potential of this country, as represented by engineers, scientists, and technical managers, is sufficient to meet any challenge. Within the membership of the scientific societies there is a vast reservoir of highly trained and experienced men. Many are already engaged in the aerospace program of the country, but there exists in other sections of the economy a great capability for emergency expansion as was convincingly demonstrated in World War II. We are certain that U.S. engineers and scientists can meet any demands that national policy may dictate. The Institute will continue its effort to improve the professional competence of its membership and stands ready and willing to assist in any or all programs in the aerospace sciences which the Congress in its wisdom sees fit to establish.

"It seems evident that the hovering performance of the machine is in reasonable agreement with simple momentum theory. In this respect it should be pointed out that slot velocities are low. . . ."

Preliminary Flight Experiments With the

Princeton University 20-Ft. Ground Effect Machine

W. B. Nixon and T. E. Sweeney

Forrestal Research Center, Princeton University

THE DEPARTMENT of Aeronautical Engineering of Princeton University has, for the past 3 years, been conducting a program of basic research into various aspects of ground effect phenomena. Reports on early work dealt with two-dimensional hovering studies of the peripheral jet. Later work, soon to be released, includes the two-dimensional study of open plenums in simulated hovering flight. Three-dimensional experimental results looking into scaling and the effect of the boundary layer within a peripheral jet are also soon to be reported upon, along with certain stability and control results from static and wind-tunnel experiments.

In conjunction with this experimental effort with static and wind-tunnel models, Princeton has constructed two manned ground effect machines for the purpose of examining certain stability and control schemes, and thereby acquiring a feeling for overall GEM problems.

The first of these machines, the Air Scooter, was built to examine the feasibility of kinesthetic control; the other—a 20-ft.-diameter peripheral jet machine to examine stability, control, and performance—has been in operation for approximately 2 months. Our operational experiences and the preliminary experiments conducted with this second machine form the subject of this paper.

A substantial portion of the following discussion deals with momentum drag. This component of overall drag is of considerable interest to the Princeton group since the very nature of an air-eating device, such as a ground effect machine, implies a marked drag due to this ingestion of air. During the recent Ground Effect Symposium at Princeton (October 21–23, 1959) it was evident from the results presented and subsequent discussions that the two performance characteristics having the most influence on the future of the high-speed GEM are the nature of the lift change with forward flight and the magnitude of the momentum drag. R. Kuhn of NASA, Langley, the first to make a drag breakdown obtained from three-dimensional forward flight experiments, reported momentum drags considerably less than anticipated—although still significant. Princeton work with the 20-ft. machine (P-GEM) generally confirms the NASA results regarding a lower momentum drag than one would compute based on zero momentum recovery. It is interesting and

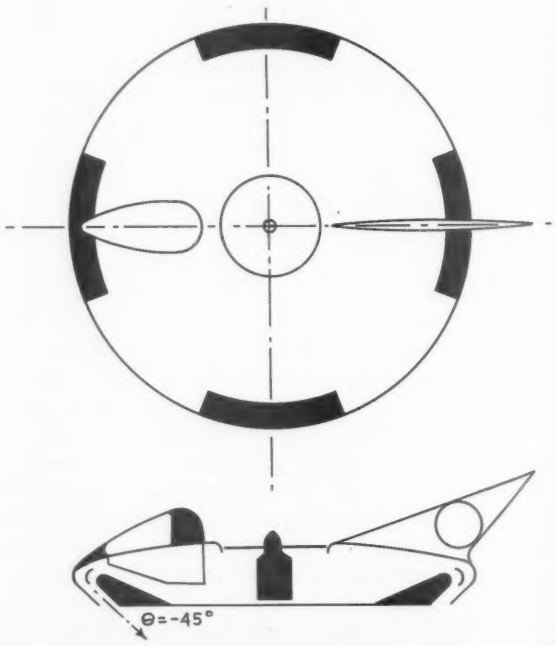

Fig. 1. Schematic layout of P-GEM.

The Princeton University research program dealing with Ground Effect Phenomena is sponsored by the U.S. Army, TRECOM, and is under the leadership of Prof. Courtland D. Perkins, Chairman of the Department of Aeronautical Engineering.

The authors wish to acknowledge the contributions made by M. P. Knowlton of Princeton University to the momentum drag analysis.

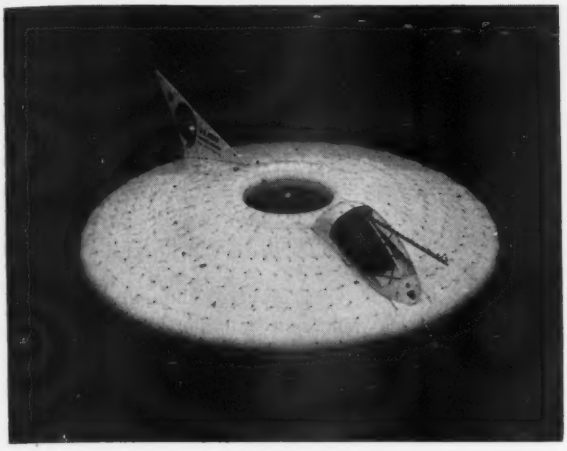

Plate A.

Mr. Nixon is a Research Assistant in the Department of Aeronautical Engineering. He received a B.E. degree in mechanical engineering from Yale University in 1952, and attended Princeton University as a graduate student until 1954, at which time he entered the USN and served as a naval aviator. In 1958 he returned to Princeton and has been working in the ground effect research program since that time.

Mr. Sweeney is a Senior Research Associate in the Department of Aeronautical Engineering. He received a B.S. degree in aeronautical engineering in 1943 from the University of Alabama and a M.S.E. degree from Swarthmore College in 1951, at which time he joined the research staff of Princeton University. His experience is predominantly that of an experimental researcher in the field of subsonic aerodynamics. He is presently project engineer of the Princeton ground effect research program.

significant that this appears to be so, and it is of primary importance to understand the reason for the apparent momentum recovery. Certain studies have been made with the P-GEM, the results of which suggest the nature of this momentum recovery.

Other experiments with this machine include the measurement of control moments and control rates about each of the three axes, a measurement of augmentation ratio and a comparison with theory, and, finally, a comparison of the full-scale augmentation ratio curve with that of a 1/12 scale model.

Discussion

P-GEM, General

The P-GEM is circular in planform and is equipped with a single annular jet and four radial slots. The radial slots, intended to impart static stability to the machine, have been found unnecessary at the altitudes so far achieved and are therefore sealed off. A view of the P-GEM appears in Plate A.

The pertinent characteristics of the P-GEM are as follows:

Planform, circular
Diameter (overall), 20 ft.
Diameter (base), 18 ft. 2 in.
Area (slot), 19.3 ft.^{2}
Area (inlet), 12.5 ft.^{2}
Propeller (Sensenich, custom made), 4-ft. diam.
Engine (main), Nelson H63B,43 hp.
Gross weight (including pilot and fuel), 1,070 lbs.
Weight (empty), 850 lbs.
Engine (tail rotor), Power Products 5 hp.

Performance

Maximum ground clearance, 12 to 14 in.
Maximum speed, 20 to 25 m.p.h.

Fig. 1 shows a schematic representation of the machine. Control is achieved about the normal axis by a tail rotor mounted on a 5-hp. engine. The entire engine swivels through 180° and is mechanically connected to the rudder pedals. Longitudinal and lateral control are achieved by means of control vanes located in the annular nozzle. The peripheral location of these vanes is shown in Fig. 1 (blackened areas in plan view), and a detailed view of their operation is shown in Fig. 2. It will be observed that the vanes operate as a butterfly valve when rotated from the normally open position. In the open position they are intended to serve as corner vanes to turn the flow more efficiently. One group of control vanes is located on the forward periphery to produce nose down pitch; another group located aft produces nose up pitch. In a similar manner the tip vanes control right and left roll. Each set of vanes is actuated by an electric servo, inputs to which are made by the pilot by means of a formation stick in the cockpit. Horizontal forces required to move the machine in any direction are generated by the appropriate tilting of the craft by means of the control vanes. Vane operation is proportional to stick movement; however, the stick/

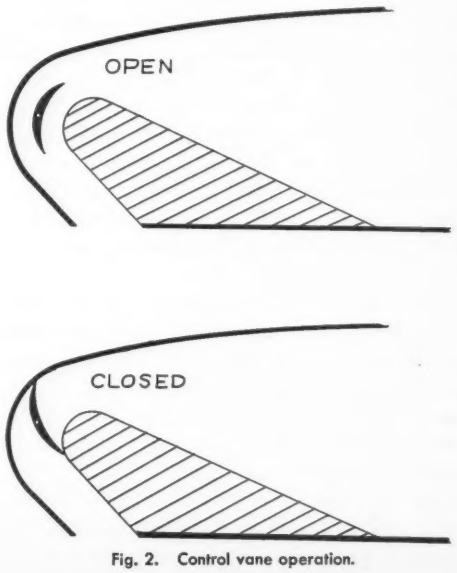

Fig. 2. Control vane operation.

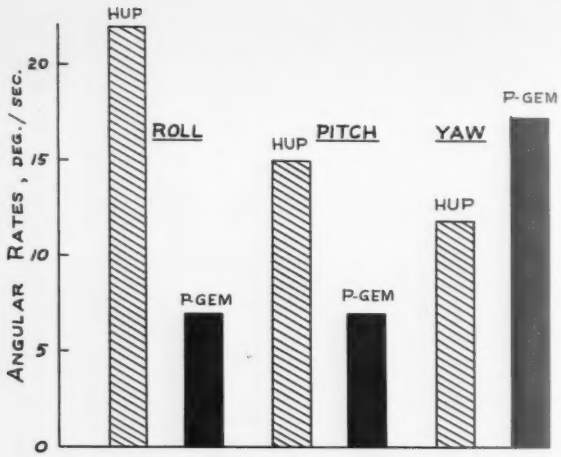

Fig. 3. Control rates, HUP-1 vs. P-GEM, hovering flight.

vane displacements are not linear. But neither is the throttling effect of a butterfly valve linear. It is not yet known how nonlinear the total system is in regard to control moments produced per increment of stick displacement.

Control

The overall control of the P-GEM can be discussed from the point of view of its ability to create horizontal components of force that provide the propulsive and braking effort, as well as those required to curve the flight path in the horizontal plane. Control may also be discussed in terms of the control moments available in roll, pitch, and yaw which, when combined with control lags, response rates, and inherent stability, give the pilot control over the attitude of the machine. This section will discuss aspects of both of these problems.

The P-GEM has been designed to generate the required horizontal force components by tilting the whole machine in the same manner as does the helicopter. These forces are therefore seriously limited by the attitude at which it flies and the requirements for ground clearance. For the 12–14 in. of hovering altitude presently available to the P-GEM, the maximum angle of pitch and roll is about 4 deg. limiting the forward speed to about 20–25 m.p.h. and the horizontal force components available for curving the path to about 7 per cent of the gross weight. This force is not too bad with relation to the low available forward speed, but limits severely the possibility of maintaining straight flight paths in cross winds of 15 m.p.h. and above. This situation will be improved considerably with the addition of more power. We are presently increasing the power from 43 to about 180 hp., which will permit estimated hovering altitudes of about 3 ft. This, in turn, will permit higher speeds, perhaps up to 40 m.p.h., and the attainment of tighter flight path control, particularly with reference to cross winds.

The second aspect of control that has been studied is the pilot's ability to control the attitude of the P-GEM to permit it to realize its present performance capability. This is, of course, a more sophisticated problem as it deals with the gross magnitude of the control moments that can be generated, the dynamics, elasticity, and hinge moments of the control system, and the aerodynamic phenomena dealing with lags, all closely related to the inherent stability of the machine while flying in the deep ground effect. The overall assessment of this aspect of control is ultimately related to the pilot's opinion, although some aspects of the transient response are of interest.

First of all, the gross control moments available through full stick deflection in hover have been measured by opposing full control application with asymmetric weights. It was found that the maximum pitching and rolling moments in hover were approximately 470 ft.lbs. Because of the severe limitation of the bank angle, sufficient time was not available to achieve a steady-state rolling or pitching velocity. However, some of the maximum transient rates experienced were measured with indicating rate gyros. These rates are compared against similar angular rates measured on a HUP-1 helicopter under test by the Department and considered only marginally acceptable. It must be kept in mind that the HUP-1 rates are fully developed steady-state responses while for the P-GEM they are only the maximum measured. Comparison of these results indicates that higher rates might be desirable and thus confirm pilot opinion, at least to a degree.

A factor that is probably important to the pilot's feeling that higher rates of roll and pitch would be desirable is the fact that there appears to be a significant lag between the application of the control at the stick and the actual achievement of a finite response. Whether this is due to mechanical lags, elasticity in the control mechanism, or nonlinearities in the aerodynamic

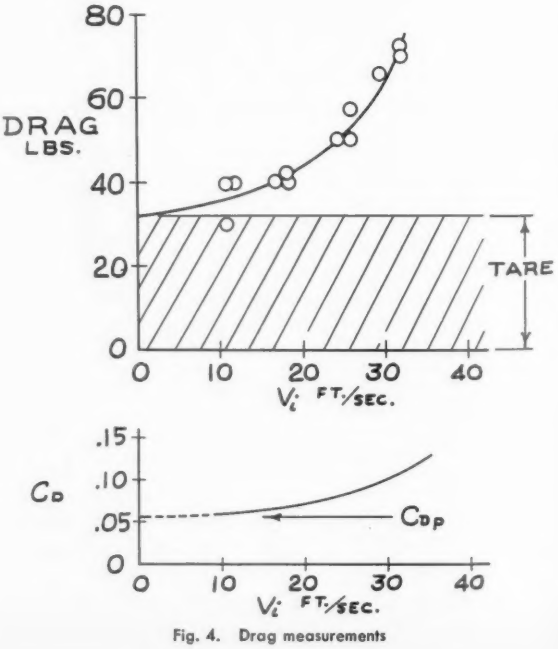

Fig. 4. Drag measurements

development of moments is not known as yet. Actually, the low altitude initially achievable with the P-GEM places it in a regime where the hovering stability is quite adequate. Under these conditions, the lags and the somewhat low response rates do not hinder a pilot from controlling it to the limit of its present capability. The addition of more horsepower, presently planned, will permit the machine to hover at an altitude where this stability will have just about vanished, and at this time these transient control shortcomings will have to be corrected.

It should be noted in Fig. 3 that the maximum yaw rate compares very favorably with the HUP-1. This is a more valid comparison since both rates are steady-state maxima achievable with the application of full control. Pilot's opinion also supports the contention that the yaw control of the P-GEM is adequate.

In summary, then, the present altitude capability of the P-GEM limits the forward speed to about 20–25 m.p.h. and also permits inadequate side force development, particularly with reference to flying the P-GEM in cross winds. More power will improve both the speed and control force available. The present transient response of the overall control system is adequate, but it has some shortcomings that will probably be unacceptable when the machine flies at higher altitudes with lower stability levels.

Drag Experiments

In order to measure full-scale drag, a 30-ft. boom was fitted laterally across a jeep from which a 50-ft. cable was attached to a glider tow hook on the nose of the P-GEM. A cable tensiometer included in the system thus yielded direct drag measurements. For these experiments the tail rotor engine was not operated. A series of runs was made up and down the Forrestal runway over a speed range of from 10 to 30 ft./sec. The results of these experiments are shown in Fig. 4. The tare values shown in the Figure result from the 2° nose up trim attitude of the P-GEM during these measurements. These drag values were reduced to coefficient form based upon the total planform area of 300 sq.ft. and are plotted in the lower portion of Fig. 4. It is seen that the drag coefficient increases in a pronounced manner with velocity. The coefficient curve was extrapolated to zero velocity, and this value was assumed to be the parasite drag coefficient of the machine. Curve C of Fig. 5 was constructed from this minimum drag coefficient and represents the parasite drag variation with velocity. Curve B (Fig. 5) is transposed from Fig. 4 and is the experimentally determined drag variation with velocity. Curve A (Fig. 5) represents the parasite drag curve added to the computed momentum drag. The momentum drag was computed on the basis of simple theory assuming zero momentum recovery, and is based upon a mass flow measurement through the machine of approximately ±10 per cent accuracy.

It seems evident from the differences between curves A and B that there is some momentum recovery. It is

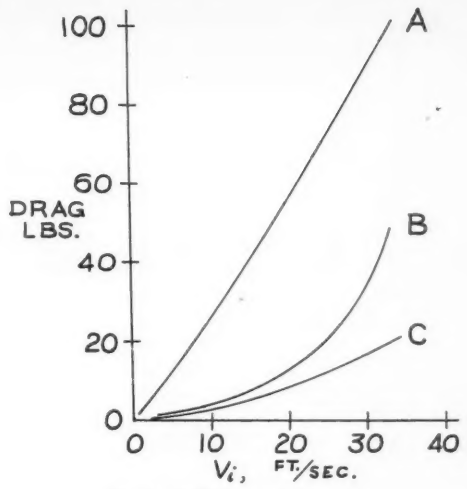

Fig. 5. P-GEM drag breakdown.

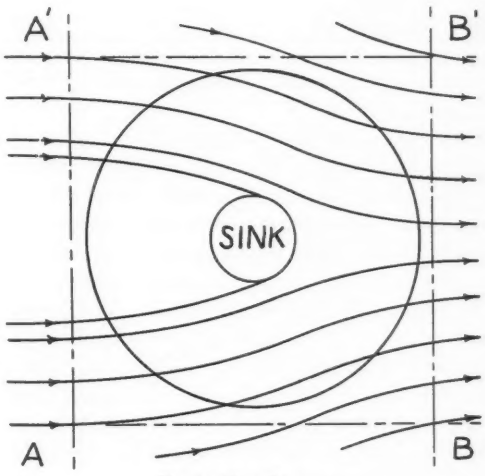

Fig. 6. Flow diagram.

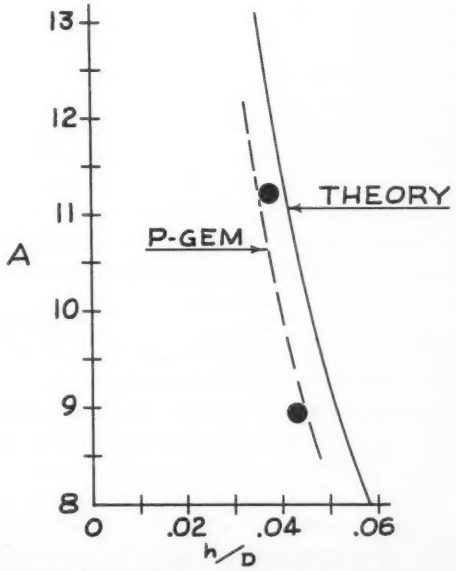

Fig. 7. Augmentation ratio comparison.

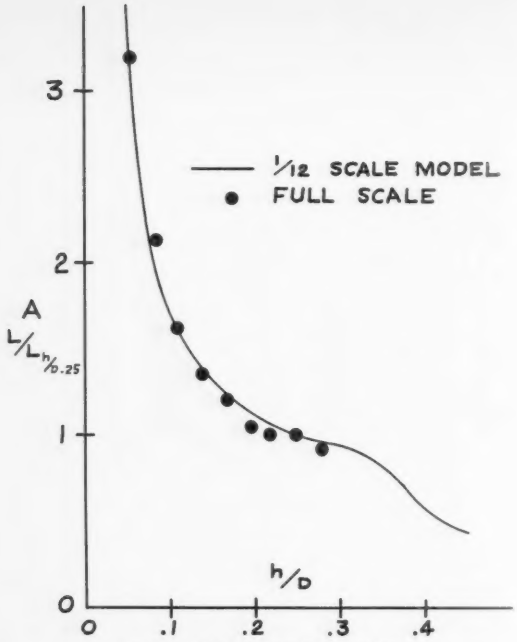

Fig. 8. Model - full-scale comparison.

perhaps reasonable to expect some recovery of momentum from the ejected air, even though it suffers considerable losses due to mixing and impingement upon the ground. This, however, does not appear to satisfy the magnitude of the spread of curves A and B, particularly when one observes the tendency of curve B to increase in slope, with increasing velocity, at a greater rate than curve A. An examination of these two curves gives the distinct impression that they might intersect or become tangent at a not very much higher velocity than the maximum achieved. This is not the only evidence which gives rise to the suspicion that there is another factor, which is a function of velocity, influencing an apparent momentum recovery.

This other evidence can best be described as the effect of the presence of the sink on the entire flow field over the machine. It is reasonable to expect that the total drag would be less than parasite drag plus momentum drag since the sink which produces the momentum drag also changes the entire flow field about the machine, and it seems possible that the altered flow could be beneficial from the drag aspect. Fig. 6 is a schematic diagram of the observed flow (by means of tufts and smoke) over the upper surface of the P-GEM. The diagram is somewhat idealized and exaggerated for purposes of simplicity of presentation, but it is a general representation of what appears to be a dominant flow condition. The quantity of ingested air is shown passing over the forward control volume boundary A-A^1 and into the sink. To help make up for this ingested air, however, additional flow is aspirated in through the side boundaries of the control volume across boundary B-B^1. As forward speed increases, the effect of the sink on the flow decreases, thus accounting for the apparent convergence of curves A and B of Fig. 5. Admittedly Fig. 6 is only a two-dimensional slice of a complex flow, and it should be emphasized that the foregoing drag discussion is based upon tuft observations and upon the measurements presented in Figs. 4 and 5. It is our best deduction, at the present, of the mechanism of the apparent momentum recovery, and it is offered as a suggestion for consideration by others.

Lift Augmentation

In order to compare the P-GEM's hovering performance with theory, mass flows through the machine were measured together with height. To do this, the slot was raked at eight stations around the periphery and the results averaged. Altitude was measured at three stations simultaneously and the results averaged. Both of these measurements were somewhat difficult to make accurately; however, it is believed that the results are within ±10 per cent accuracy for the two experimental points shown in Fig. 7. It was, unfortunately, not possible to acquire more data in the time available. The solid curve in Fig. 7 is a plot of Chaplin's simple momentum theory, and the dashed curve represents an estimate of the P-GEM's augmentation ratio curve based upon the two data points.

Fig. 8 is a preliminary attempt to compare the full-scale hovering performance with that of a 1/12 scale model of the P-GEM. Lift of the full-scale machine was measured over a range of altitudes up to approximately a quarter of a diameter by suspending the machine from an overhead hoist and reading the apparent weight of the machine on a strain-gage load cell located in the suspension system. These data points were measured at a constant power setting. The solid curve of Fig. 8 representing the 1/12 scale model was determined by means of a more appropriate model static test stand. Of particular interest was the hump in the model lift augmentation curve. Since there are plans to increase the power in the P-GEM to reach altitudes in the vicinity of this hump, it was of some importance to know if the full-scale machine would have a similar augmentation curve.

In order to compare the shapes of these curves, without having accurate mass flow measurements through either the model or full-scale machine for all of the altitudes considered, results were reduced to the parameter $L/L_{h/D.25}$.

Fig. 8 indicates a rather close agreement in the shape of the two curves and gives some promise that the full-scale machine will have a hump in the augmentation ratio curve quite similar to that of the model.

Conclusions

The work reported and the deductions presented in this paper are of such a preliminary nature that conclusions, as such, should be considered as tentative.

As far as the controllability of the P-GEM is concerned, it is evident that better longitudinal and lateral control is desirable; however, directional control seems to be quite adequate.

The interesting problem of momentum drag is still

(*Continued on page 58*)

The Convair 880 was flight flutter tested a year before it was built!

This contradictory statement serves to introduce the subject of this article. A complete 1/20th scale, dynamically similar model was "flown" in the Southern California CWT transonic test section for flutter testing beginning in March, 1958.

Flutter Testing the 880 in a Transonic Wind Tunnel

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Mr. Mac Lellan was awarded a Bachelor of Science degree in Aeronautical Engineering by the University of Michigan in 1950 and has done graduate study in the field of mathematics and dynamics. He has been employed by Convair (San Diego) since his graduation from the University. His responsibilities include direction of all work associated with flutter models; solution of dynamic problems associated with aerodynamic and nonaerodynamic airframes; and development of integrated instrumentation, check-out, and recording systems for experimental tests of dynamical systems.

CONVAIR was not the first to attempt wind-tunnel flutter testing a complete aircraft model at transonic speeds, but they were, fortunately, the first to do so successfully. The testing was not, however, without mishaps which included the complete loss of the first such model, due not to flutter but to the failure of one part on the supporting sting. I will first supply the reader with the background of this project before launching into the test itself.

Considerations in the Use of a Wind-Tunnel Model

It is known to those familiar with the flutter problems associated with transonic speeds that there are no analyses available to predict accurately the flutter behavior of aircraft in this speed range. This results from the unsteady flow characteristics which exist near the speed of sound. Prior to the existence of a shock wave and subsequent to its appearance, analysis yields reasonably good agreement with experimental results. This situation naturally leads the aeroelastician to look elsewhere for some means to predict the transonic flutter characteristics of an aircraft. The most obvious is the use of a wind-tunnel model. There are many drawbacks to this apparent panacea for the flutter analyst, including:

(1) Difficulty of defining precisely full-scale characteristics to be modeled.

(2) Small size of model, dependent upon wind tunnel to be used.

(3) Scarcity of tunnels having high dynamic pressures available in the transonic speed range and tunnels which also permit using reasonably sized models.

(4) Long lead time from initiating project to obtaining test results.

(5) High cost of precise models which is aggravated by the strong possibility of losing the model before the tests are completed.

(6) Fitting instrumentation into such models to provide needed data.

(7) Establishing that the model satisfactorily duplicates the important full-scale characteristics as desired.

(8) Operation of model and/or wind tunnel.

A great deal of work has been done in testing of airplane components such as wing, vertical tail, and horizontal tail. These tests have always suffered from certain shortcomings:

(1) Neglect of the elastic and aerodynamic effects of other portions of the aircraft on the item in question.

(2) The antisymmetric modes of a wing or horizontal tail must be neglected when a semispan model is utilized.

(3) The influence of the airplane's rigid body modes are neglected.

Selection of a Model

During initial planning, a number of component models were considered. The major deterrents to these plans included not only the three noted above, but also the long lead time as noted earlier and the difficulty of deciding which characteristics should be modeled; the effect of the airplane's rigid body modes—although not a deciding factor—were a consideration in the decision since they were near the structural frequencies of the airplane.

In view of the facts noted above, and since this was Convair's first experience in transonic swept-wing airplanes, it was decided that a complete airplane model should be employed to investigate the flutter characteristics of the airplane. The tunnel chosen was the Southern California Cooperative Wind Tunnel (CWT) which has a transonic test section measuring 7.5 ft. by 9.75 ft. This dictated the model size as 1/20th that of the full scale to preclude adverse aerodynamic effects of excessive blockage of the test section. Since the maxi-

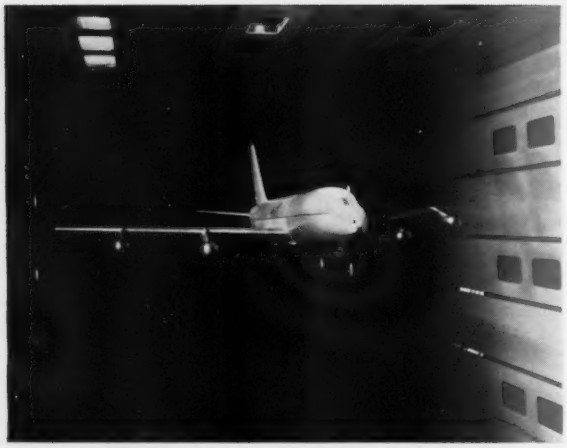

Fig. 1. 1/20th scale 880 flutter model mounted for test in CWT transonic test section.

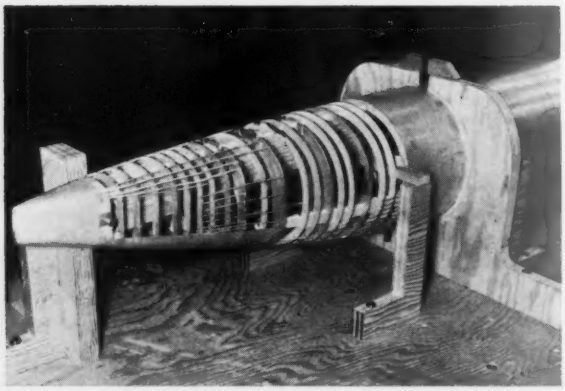

Fig. 2. Partially completed fuselage showing wood and aluminum bulkheads and aluminum stringers.

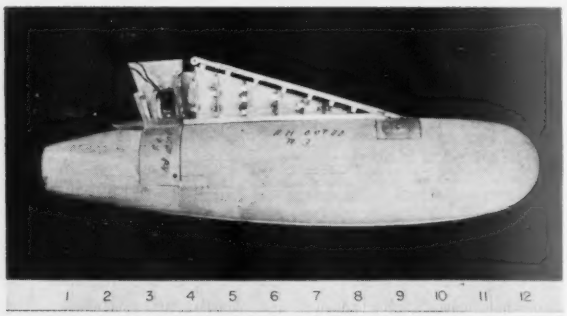

Fig. 3. Structural detail and instrumentation on the engine pod-pylon.

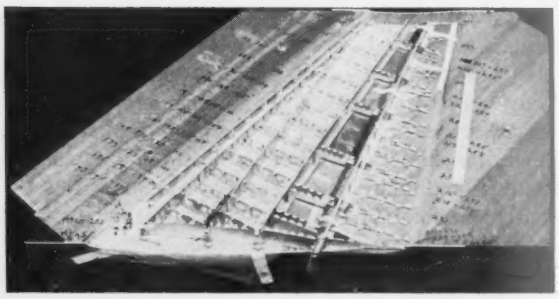

Fig. 5. Vertical fin and rudder showing aerodynamic balance board simulation.

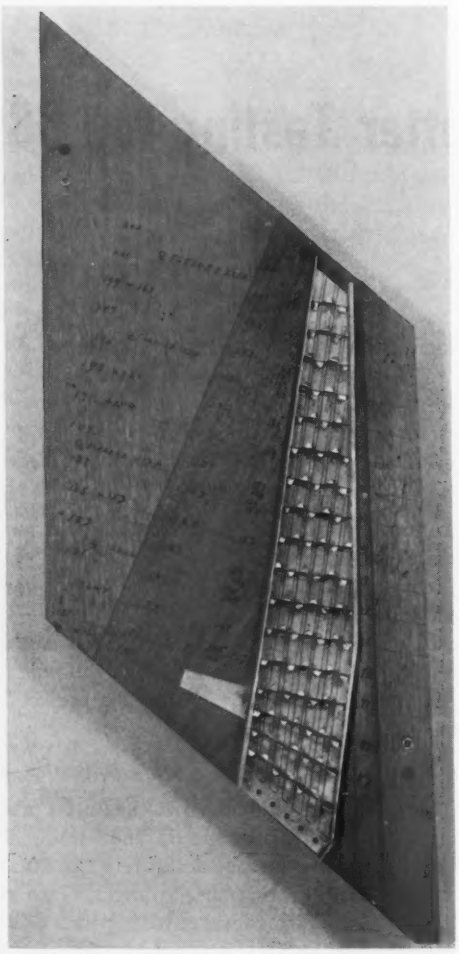

Fig. 4. Stabilizer prior to final assembly in baking mold.

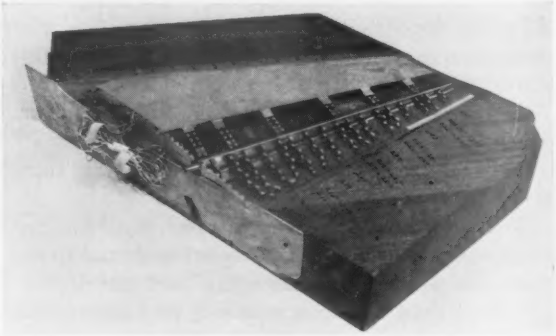

Fig. 6. Vertical tail after final skin bonding on fin.

mum dynamic pressure which can be developed by the CWT at the Convair 880's limit dive speed corresponds closely to the limit dynamic pressure of the airplane, it was necessary that the ratio of airplane flight air density to model flight air density be unity. This ratio of unity imposes an extreme problem to the designer which will be elaborated upon later. It was further decided that the model should be sting-mounted with a model-sting attachment resembling a ball joint, permitting all rotary degrees of freedom, within set limits. The vertical and lateral rigid body degrees of freedom were simulated by appropriate design of the sting. The initial model is shown in Fig. 1 mounted in the test section of CWT prior to test.

The model's design parameters are

Reduced frequency $= (b\omega/v)_{\text{model}}/(b\omega/v)_{\text{full scale}} = 1$
Mass ratio $= (m/\rho b^3)_{\text{model}}/(m/\rho b^3)_{\text{full scale}} = 1$
Density ratio $= \rho_{\text{model}}/\rho_{\text{full scale}} = 1$
Velocity ratio $= v_{\text{model}}/v_{\text{full scale}}$ assumed $= 1$—i.e., temperature variation is neglected
Scale ratio $= b_{\text{model}}/b_{\text{full scale}} = 1/20$

where b = characteristic length, ω = structural frequency, and m = mass of model or full scale.

The design of the model was "slightly" simplified by the fact that the skins and integral stringers of the full scale were scaled to model size and chemically etched from magnesium. Magnesium was used instead of aluminum on the airplane since its modulus or elasticity is 0.65 that of aluminum, thereby permitting the use of a thicker skin to obtain the same EI and GJ. This can be shown by considering the mass, spring constant, and frequency relationship:

$$\omega^2_b = k_b/m \quad \text{for bending}$$
or
$$\omega^2_t = k_t/I \quad \text{for torsion}$$

where k_b = bending spring constant, k_t = torsion spring constant, and I = mass moment of inertia.

Since $k_b \approx EI_b$ and $k_t \approx GJ$
$I_b \approx m\omega_b{}^2/E$ and $J \approx I\omega_t{}^2/G$

where I_b = area moment of inertia, J = polar moment of inertia, E = Young's modulus, and G = shear modulus.

Therefore, for requirements of a given mass and frequency, the area moment of inertia (and thereby the skin gage) may be increased if the E and G are decreased. This is particularly true on the Convair 880 since it is designed with most of its strength in the skin to preclude fatigue problems. The use of magnesium for the model's primary structure became necessary because the use of aluminum would result in material so thin as to be impractical to work with.

Figs. 2 through 6 indicate typical model construction. The assembly of the model utilized adhesives of a modified epoxy type. Prior experience had indicated epoxies per se to be prone to fatigue failure due to brittleness after cure. The adhesive used had some resilience, which was detrimental in a minor way relative to creep but was advantageous in permitting long fatigue life. The construction techniques are much like those of the full scale, including utilization of extensive jigs and tooling.

Caution had to be exercised in the application of adhesives because of the close tolerance on weight. Since the 880, like other commercial craft, is designed to a low load factor and the structure is extremely efficient, it is necessary to duplicate the airplane structure almost exactly in order to keep the weight as low as possible. In addition to this, it should be remembered that, because of the way in which the model was built, a relatively low strength attachment was all that could be obtained since riveting and bolting would be impractical. This means the designer would provide more area at joints for bonding than is correspondingly provided on the airplane. Naturally the weight goes up in consequence. To help alleviate the problem, the nonstructural portions of the airplane were replaced by balsa wood wherever possible on the model.

It is apparent from Figs. 7 and 8, as well as those preceding, that the design task associated with this model

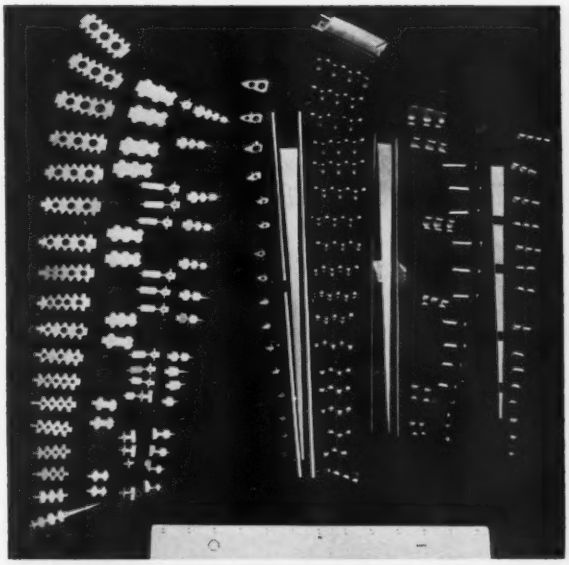

Fig. 7. Parts for one side of horizontal tail.

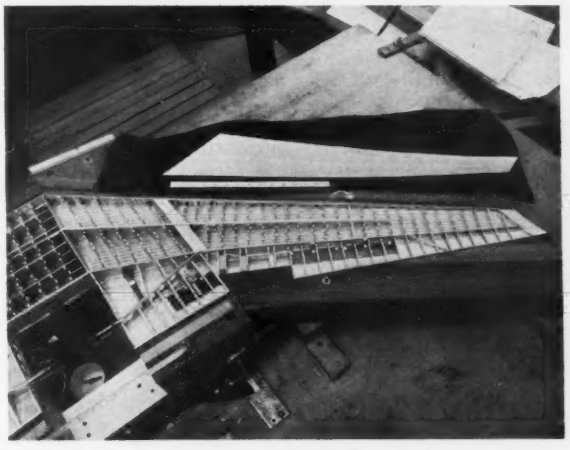

Fig. 8. Model wing prior to bonding on lower skin.

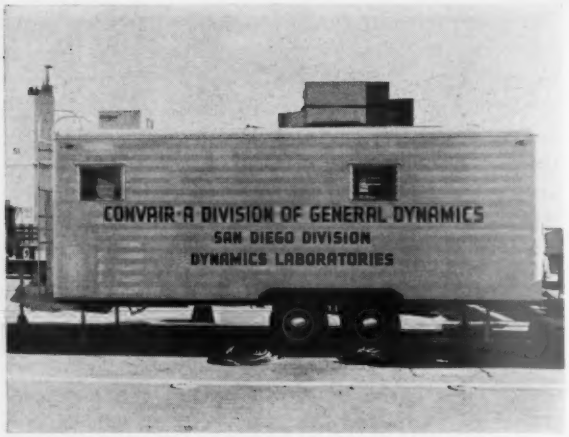

Fig. 9. Instrumentation trailer.

was a formidable one. Many clever and unique design developments helped make this model practical:

(1) Transfer of model drawings onto plates which are cut into dies for stamping the many ribs and spar webs.

(2) Detail layout and transfer of stringer arrangement on the skins onto actual construction material for subsequent chemical etching.

(3) Layout of strain-gage locations and pads for their application and wiring route.

(4) Sting design utilizing pneumatically engaged hydraulic damper between model and sting for emergency use.

(5) Design of integral fuel tanks to permit use of hydraulic fluid to simulate fuel.

(6) Design of a sting-instrumentation arrangement permitting monitoring the pitch, roll, and yaw angles of the model relative to the sting.

(7) Inclusion of a balance system in the model sting for visual monitoring of life, side load, pitching moment, yawing moment, and rolling moment by the test conductor.

(8) Removable, flexure pivot mounted, control surfaces.

(9) Remotely trimmable horizontal tail simulating the action of the full-scale airplane.

(10) Shock exciter inside fuselage which was pneumatically powered from a remote position.

Instrumentation and Other Features

The instrumentation problems associated with these models were not unlike those encountered in component testing. Primary instrumentation was the strain gage with stabilizer position indicated by a slide wire potentiometer. The unique feature of instrumentation was the monitor console with indications and controls as follows:

(1) Dials indicating lift force, side force, pitching moment, yawing moment, rolling moment, and stabilizer position.

(2) Lights indicating pitch nose up (adjustable contact to indicate pitch with respect to the sting of approximately 1/2 deg.); pitch nose down, set as above; roll right, set for 1/2-deg. roll from horizontal; roll left, set as other roll light; yaw right, set for 1/2-deg. yaw from parallel to sting; yaw left, set as other yaw light; lock engaged, pitch, roll, and yaw; and lock disengaged, pitch, roll, and yaw.

(3) Controls for stabilizer drive; lock-unlock, pitch, roll, and yaw; exciter(s); cameras, cine or TV; and provisions for aileron control and sting yaw control.

In addition to this instrumentation, there were a number of other unique items:

(1) A unit which continuously monitors the signal level of 16 channels of strain-gage data. Should any of these channels have a signal exceeding a preset level, the model-sting lock is automatically engaged and any excitation is automatically stopped. Also all the recorders and cameras which may not be operating are started.

(2) A multiplexing unit permitting tape recording of up to 100 channels of data and simultaneously 16 channels of oscillograph and twelve channels of direct-writing recording (brush).

(3) A patching system permitting monitoring any of six channels on three dual-beam scopes, as well as simplified switching of channels to the oscillograph and/or brush recorders.

(4) Remote TV controls and monitors for up to six TV cameras.

(5) Controls for two electromagnetic excitation systems.

(6) Transformers and power supplies to convert 230-volt, 3-phase 60 cycles to (a) 115-volt single-phase 60 cycles, (b) 28-volt d.c., and (c) 28-volt 400 cycles.

(7) Portable developing unit for oscillograph records.

(8) An intercommunication unit for test director/test section/control room coordination.

All of these units, as well as the equipment trailer in which they are housed, are shown in Figs. 9 through 13. The trailer has been designed to permit its use in any wind tunnel or test site. Only 230-volt, 3-phase 60-cycle power needs to be supplied. Sufficient cable length is supplied to permit hookup to test section and tunnel control room from any reasonable distance.

Prior to wind-tunnel test, the initial model was vibration tested in a manner similar to that utilized for the full scale. No stiffness measurements were made since no data were available for comparison. The support system for the model vibration tests is shown in Fig. 14. The suspension frequency is adjustable with interchangeable springs for various model gross weights. The shaker system consisted of extremely light coils bonded to the wing. These coils are settled in concentric ring magnets which could be adjusted to any angle for support of the coils. Fig. 15 shows these supports. Of the various systems investigated, this system incorporated what was considered the optimum of light weight of moving mass, larger force, and greater frequency capabilities. The vibration modes were established by using two accelerometers of very light weight (Glennite type AVR 250). It has been found that using crystals such as salt or sand can give erroneous

Fig. 10. Interior view of instrumentation trailer from rear door.

Fig. 12. Front of trailer showing tape recorder and multiplexing unit.

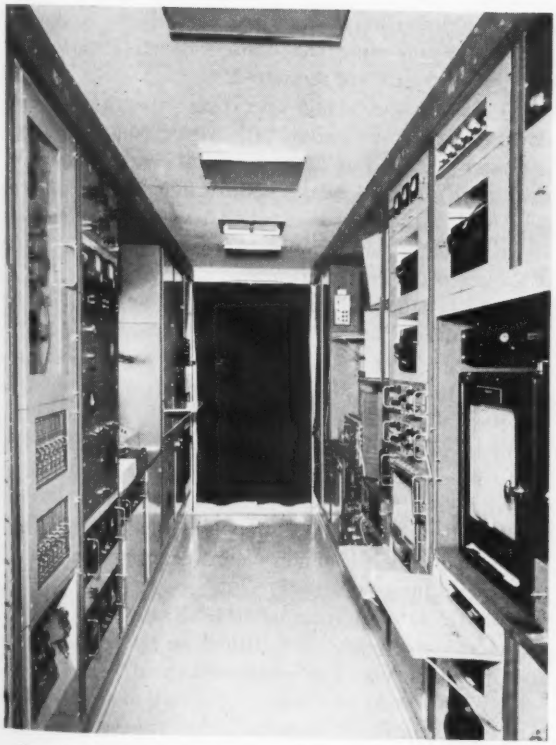

Fig. 11. Interior view of instrumentation trailer from front end.

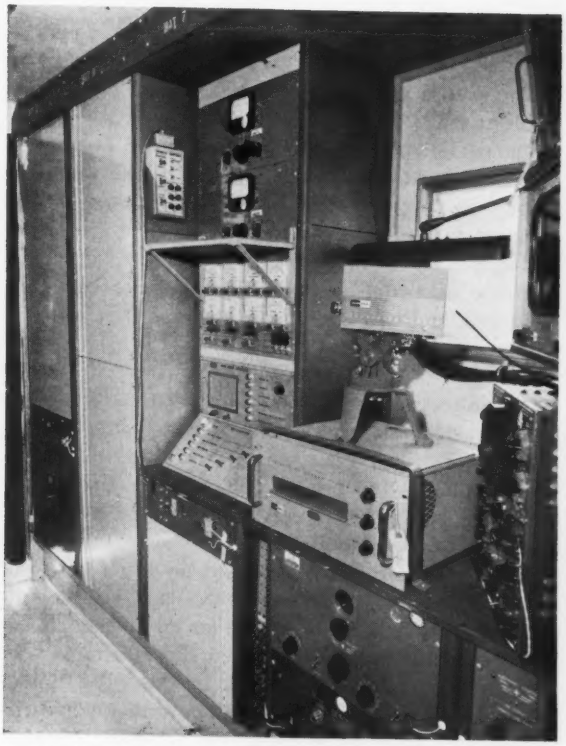

Fig. 13. Test conductor's station in instrumentation trailer.

Fig. 14. Model support system for vibration testing.

Fig. 15. Shaker magnet supports.

nodal patterns when compared with those established with accelerometers. By utilizing a dual-beam oscilloscope it was possible to adjust the scope signal to be identical for the two accelerometers located at one point on the model. One accelerometer was then moved to various parts of the model and the relative amplitude and phase relationship could be determined with respect to the signal on the scope. This technique also permits:

(1) More precise location of points of phase shift.

(2) Detection of variation in force output of the shaker.

(3) Determining equal excitation at similar points on either side of the model.

The models are vibration tested just prior to testing in the tunnel.

The model was first tested in the Convair Low Speed Wind Tunnel to ensure that no difficulties would be encountered in operation of the model once it was mounted in the transonic tunnel. This test also permitted checkout of camera locations for best observation and ease of model control. The indicator lights for pitch, roll, and yaw were also adjusted at this time.

"Flying" the Model

One important factor to consider in the "flying" of such a model is the relationship of model mass to aerodynamic lift. The mass varies as the cube of length and the lift as the square. This means that one *g* flight requires 1/20th the lift obtained for corresponding full-scale airplane flight angles. There is also the fact to consider that for turbulent air loads the wing weight provides a relieving inertia load on the full scale which is reduced to 1/20th on the model. Since the strength problem is acute and the trim angle is so small, it becomes obvious that in the wind tunnel "flight" is a ticklish proposition. The author can attest to this after spending in excess of 100 hours "flying" these models at CWT. Of course, this task is made considerably easier by extremely capable operation of the wind tunnel at CWT.

The actual tunnel testing was facilitated by the communications setup seen in Fig. 13. Note that there are indicator lights and switches for On Mach number, Increasing Mach number or pressure, Decreasing Mach number or pressure, On pressure, Tunnel delay, Ready to run, Recording, Hold at condition, Emergency stop, Wind on, and also an intercom. A similar unit was placed in the tunnel control room.

A typical tunnel run would proceed as follows:

(1) Test conductor ascertains all is in readiness with model, instrumentation, and recorders; then he announces "Ready to run" and switches on the appropriate light to eliminate unnecessary repeats and questions. At this time the desired Mach number and dynamic pressure are requested.

(2) During the tunnel operating personnel's countdown for start, the switch "Increasing Mach number" is thrown. Also if an immediate start cannot be made, the switch "Tunnel delay" is thrown. This permits all personnel in the instrumentation trailer to be kept advised so that recorders and cameras are not operated when not necessary.

(3) After start, the tunnel operator switches off the "Tunnel delay" and switches on "Increasing Mach or pressure." After reaching conditions which were requested, the "Increasing Mach or pressure" light is switched off, and the "On Mach" and "On pressure" lights are switched on as these conditions are reached.

(4) When tunnel conditions are set, the "Hold at condition" light is lit, all the instrumentation are recorded, the "Recording" lamp is turned on, and the tunnel operating personnel record exact tunnel conditions for future correlation.

(5) After data are recorded, the "Next Mach" and/or "Next pressure" lights are turned on by the test conductor and the above procedure is repeated.

(6) In the event an emergency situation arises and is detected by the instrumentation, the "Emergency stop" light will be lighted and an immediate tunnel shutdown initiated by the tunnel operator.

During change in Mach number, the loadings on the

various surfaces are monitored on the brush recorders. The model is trimmed with stabilizer as much as possible to keep loading minimized. In the event trim changes beyond the stabilizer's strength capabilities become necessary, the sting is pitched by the tunnel operator on request of the test conductor. Certain of these trim changes are rather abrupt, and it became necessary to stop any changes in tunnel conditions until low load trim could be established.

The loss of the first model occurred when there was an unsymmetrical wing trim change which caused the model to roll and shear off the roll stop. This roll resulted in a large lateral load on the sting and subsequently the sting diverged laterally, causing complete loss of the model.

Subsequent models were naturally designed to preclude such a recurrence. They were, in fact, spring suspended on the sting. No further loss of that kind was sustained.

Test Results

The procedures and techniques developed for these tests helped make this type of testing practical and useful. The results of these tests gave Convair great confidence when the testing of the full-scale airplane began. It has been shown that such testing, although not inexpensive, can effectively forecast the behavior of the full-scale aircraft. Not only were the airplane's flutter characteristics determined, with the exception discussed below, but also the various aeroelastic trim changes and "Mach buffet" were very similar to those encountered on the full-scale airplane.

A change in fin design of the full-scale airplane was made subsequent to model construction. As a result of the high rate of design and production, it was not possible to incorporate the redesign in a new model and determine the ramifications of the change on airplane flutter stability in the wind tunnel prior to full-scale flight. It was, therefore, necessary to investigate the new fin-rudder configuration during flight test. During these tests Convair learned, as have the other jet transport manufacturers, that the use of a manual control system on a near-sonic-speed airplane involves considerable risk during flight test to determine flutter stability boundaries of nonproduction configurations. It was during one of these tests that flutter was encountered on the vertical tail, resulting in loss of a portion of the fin and rudder tip. This incident, although undesirable, has permitted Convair to establish with a certainty that a similar incident cannot occur on production airplanes which will be flown in airline service. The present fail-safe design philosophy of commercial airframe manufacturers in general precludes the presence in airline service of such configurations on any aircraft designed and built in this country.

In conclusion, the models "flown" in the tunnel indicated a smooth-flying, safe, and comfortable airplane which we may look forward to enjoying in the near future when the 880 goes into regular airline service.

✦ ✦ ✦

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Maximum-Effort - Minimum-Support Simulated Space Flights

How many hours can human reliability be extended?

George T. Hauty
USAF Aerospace Medical Center (ATC)

Dr. Hauty (M.A., Stanford University; Ph.D., University of Rochester) is an Associate Professor of Experimental Psychology in the Department of Space Medicine, School of Aviation Medicine, Aerospace Medical Center, Brooks AFB, Texas. Following a year as Research Associate at the University of Rochester, he joined the Department of Psychology, School of Aviation Medicine, in 1951, and in 1957 was assigned to the Department of Space Medicine. During the past 3 years, he has been investigating the effects upon human reliability of conditions unique to manned space operations.

SINCE THE orbital flight of advanced weapons systems will represent a drastic departure from present flight durations, it is reasonable to presume that a substantial degree of this difference will be reflected in the requirements for human reliability. This, at least, has been the presumption underlying much of our biomedical experimentation, including the investigations to be reported. In these, subjects were committed to the SAM one-man space cabin simulator for a maximum effort flight which encompassed a 24-hour or physiological day. The data reveal the joint effects of sustained work and circadian periodicity upon human reliability, magnitude of difference between individuals drawn from nonpilot and pilot populations, and differential decline in reliability attributable to different task requirements.

Cabin Characteristics

The first characteristic of the one-man space cabin simulator deserving of mention is that of mobility restriction, illustrated by Fig. 1. As can be seen, the approximately 50 cu.ft. of space available to the subject limits him to his seat. In addition to this degree of physical confinement, subject is denied visual access to the outside, and whatever noise may be transmitted, airborne or by connecting pipelines, is effectively damped by a constant internal noise level of approximately 84 db. With essentially one exception, the environmental conditions of chamber pressure, temperature, humidity, and the partial pressure of oxygen are automatically controlled permitting the subject to devote nearly all of his attention to his operator task. In the case of pCO_2, subject is merely required to exchange absorbent canisters. Continuous observation of the subject by ground personnel is permitted by a closed-circuit television system. Accordingly, a log of subject's activities and other significant events is maintained throughout the flight.

A second closed-circuit television system provides for the presentation of the operator task to be performed by the subject. The display and associated control consoles are shown in Fig. 2.

The tasks required of the subject involve the functions of spatial discrimination, perceptual judgment, vigilance, and problem-solving. Proficiency with which

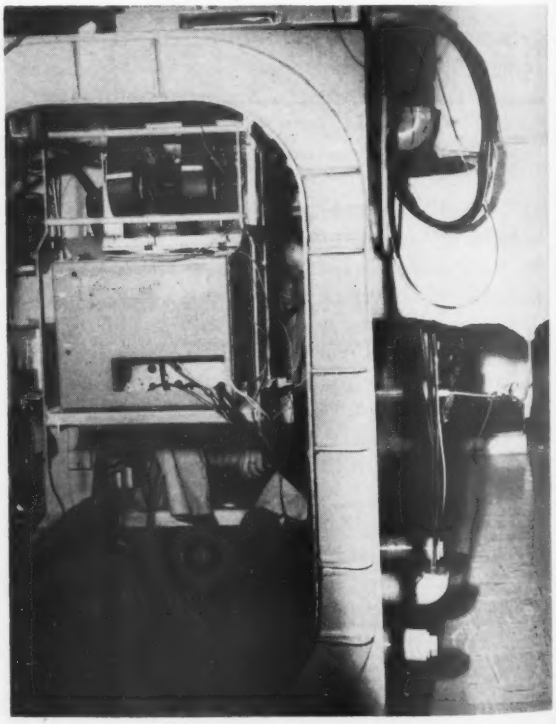

Fig. 1. Interior of SAM one-man space cabin simulator.

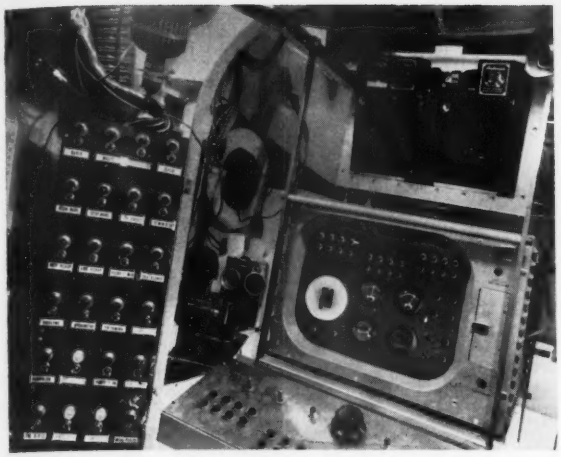

Fig. 2. Operator system and command panel.

these functions are executed is electrically recorded in terms of time—that is, the time required to solve a problem, to detect the departure of an indicator from its null position, etc.—and also in terms of the number of errors committed.

Prior to his simulated flight, the subject was given instructions and training on the operation and control of the life-support systems required for prolonged simulated flight and practice with the operator system; he was also briefed on the nature of the flight profile and its practical implications. Essentially, the flight consisted of two phases—6 hours of simulated pad time, followed by a simulated flight of 30 hours' duration. In the case of the former, subject entered the chamber at either 0800 or 2400 hours and, with the exception of occasional check-outs of instruments and procedures, devoted most of the 6 hours to sleep, reading, or rest. Immediately following this, ascent was made to a simulated 18 M ft. altitude and subject was committed to the activated operator system.

The Flight

The pertinent requirements and conditions of the flight itself were as follows:

(1) Subject was required to perform the task provided by the operator system for the entire duration of the flight. Remaining awake was to be exclusively his problem in that no attempt would be made by the ground crews to waken him.

(2) At 90-min. intervals, which were to be timed by the subject, a transit report was required. This consisted of verbally reporting chamber temperatures, oral temperature, hygrometer reading, and any comments that subject might wish, and in fact was initially encouraged, to volunteer. The amount of time permitted for such reporting was 10 min. With the exception of these reports, radio silence was to have been maintained by ground crews. Failures did occur but only when seriously stressful experiences necessitated reassuring support.

Throughout the flight, periodic recordings were made of the environmental conditions of chamber pressure, temperature, and humidity, and the partial pressures of O_2 and CO_2. In addition to these and the objective appraisal of operator proficiency, heart rate and respiration rate were also recorded periodically. As for the other environmental conditions, chamber pressure, as has been mentioned, was maintained at about 380-mm. Hg, partial pressure of oxygen at 150-mm. Hg, temperature between 77° and 89°F., and relative humidity between 30 and 49 per cent. Since the CO_2 absorbent (lithium hydroxide) was held to a minimum weight (3 lbs.), partial pressure of CO_2 increased gradually as the flight continued. When, after 15 to 20 hours of flight, the level approached or reached 25-mm. Hg, subject was signaled to insert the spare canister of absorbent in the flow system. Finally, the food stored in the chamber was of minimum amount, approximately 940 calories and weighing 350 grams. This food, however, was highly nutritious and quite acceptable to the subject. The amount of potable water was 2 liters.

From the foregoing, it should be evident that the subject was committed to what may be described as a maximum-effort - minimum-support simulated flight. Immediately following the flight, subject was examined and debriefed, then, after a sufficient lapse of time, underwent psychiatric evaluation.

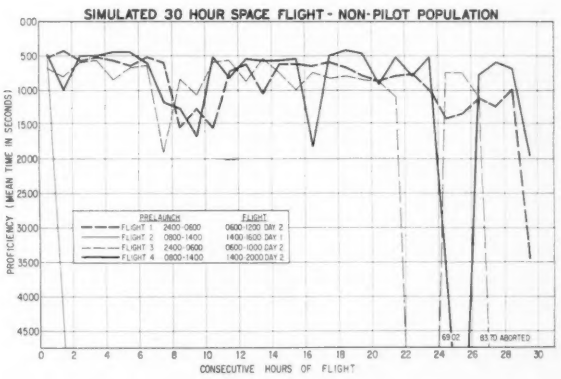
SIMULATED 30 HOUR SPACE FLIGHT - NON-PILOT POPULATION
PROFICIENCY (MEAN TIME IN SECONDS)
CONSECUTIVE HOURS OF FLIGHT
PRELAUNCH
FLIGHT
FLIGHT 1 2400-0800 0600-1200 DAY 2
FLIGHT 2 0800-1400 1400-1600 DAY 1
FLIGHT 3 2400-0600 0600-1000 DAY 2
FLIGHT 4 0800-1400 1400-2000 DAY 2
69.02
83 TO ABORTED

Fig. 3. Mean proficiency curves of nonpilot subjects.

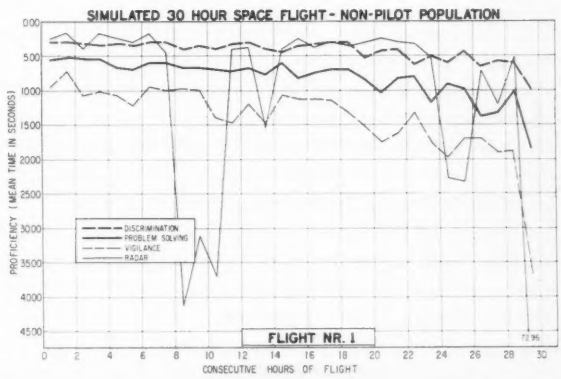

Fig. 4. Individual task proficiency attained by first nonpilot subject.

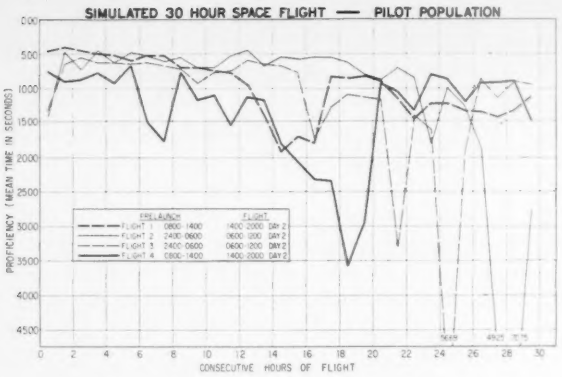
SIMULATED 30 HOUR SPACE FLIGHT — PILOT POPULATION
PROFICIENCY (MEAN TIME IN SECONDS)
CONSECUTIVE HOURS OF FLIGHT
PRELAUNCH
FLIGHT
FLIGHT 1 0800-1400 1400-2000 DAY 2
FLIGHT 2 2400-0600 0600-1200 DAY 2
FLIGHT 3 2400-0600 0600-1200 DAY 2
FLIGHT 4 0800-1400 1400-2000 DAY 2

Fig. 5. Mean proficiency curves of pilot subjects.

Test Results

Nonpilot Subjects

The subjects were volunteers drawn from two distinctly different populations. The results to be presented first are those obtained from the flights of four nonpilot subjects. These were volunteers from the professional and technical staff of the Department of Space Medicine and, as such, were well acquainted with the one-man space cabin simulator and the nature of previous research conducted with this capability. Fig. 3 presents the mean proficiency for all tasks for each hour of flight achieved by each of the nonpilot subjects. As can be seen, two of the flights had to be aborted. One subject, after a total of 7 hours in the chamber, exhibited a severe claustrophobic reaction and had to be taken out. The other subject had to be removed after 27 hours of flight because of panic induced by a severe and inordinately persistent hallucination. Of the two subjects who completed this flight successfully, one began his flight at 0600 hours and the other at 1400 hours. This represents in the course of diurnal metabolism and concommitant state of alertness an extreme temporal difference. With such a difference, we should expect to see the typical circadian phase occurring at different points on the curves. We do not see this, however, which must be attributed to the possibility that these two subjects, at least, were able to maintain a high state of alertness for an extremely prolonged period of time. It will be noted further that, beyond 20 to 22 hours of flight, proficiency begins to deteriorate abruptly and drastically. One additional point of interest concerns the marked and transitory decrement in proficiency which is seen to occur following 7 or 8 hours of flight for all three subjects irrespective of time of day. What is of specific interest is that these subjects characteristically work an 8-hour duty day.

As has been mentioned, the proficiency curves, which we have seen, represent the proficiency means of all tasks. In this sense, they indicate a composite proficiency plotting. Fig. 4 presents the proficiency with which each individual task was performed during each hour of flight by the first subject. Revealed here is a familiar observation—namely, with prolonged effort, performance at different tasks undergoes differential decline. In the case of this particular subject, the greatest deterioration of proficiency occurred in his vigilance task. This consists of simply throwing a switch whenever one of three aircraft-type indicators creeps beyond its null position. While this is a simple task, the requirement for alertness is quite severe because of the slowness with which the indicators drift. Substantial decrement in proficiency also occurs in the case of the radar reconnaissance task. For this task, as compared with the others, fluctuation of proficiency is extreme. This task, in addition to requiring a high degree of vigilance because of the minuteness of change, also requires perceptual judgment for the detection or determination of match between scope presentation and the referent itself. For the other task, discrimination and problem-solving, where the events are signaled by lights which are very gross cues, deterioration of proficiency is relatively much less. These observations are generally characteristic of most subjects that have been committed to prolonged simulated flights in the chamber concerned.

Jet Pilots

In marked contrast to the proficiency of the nonpilot subjects are the curves obtained from the volunteers who were drawn from a population of highly experienced

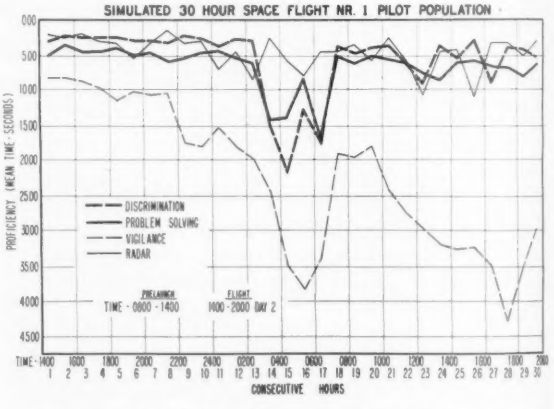

Fig. 6. Individual task proficiency attained by first pilot subject.

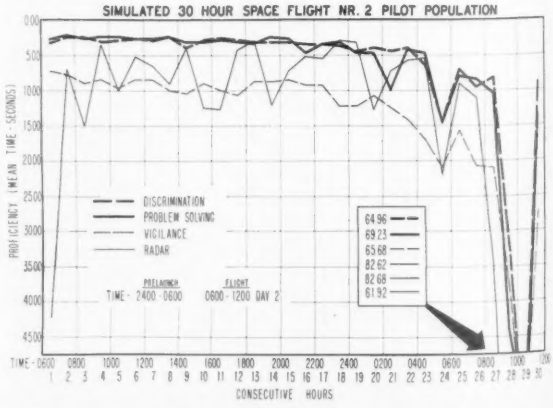

Fig. 7. Individual task proficiency attained by second pilot subject.

jet pilots presently on active tactical duty. These curves, which are shown in Fig. 5, reveal interesting differences between flights which began at 1400 hours and those beginning at 0600 hours. In the case of the former, a rough approximation to the normal circadian phase is evident—that is to say, the most abrupt and greatest decrement in proficiency occurs during that period of local time which these subjects usually devote to sleep. With recovery, as it were, from diurnal variation, proficiency returns to, or nearly to, previous levels and continues at these levels for the remaining 10 or 12 hours of flight. In the case of the flights beginning at 0600 hours, proficiency appears to be maintained at relatively high levels throughout the period of local time typically devoted to sleep. Following 20 to 25 hours of flight, however, both subjects, having exhausted their repertoire of techniques for remaining awake, fell asleep for appreciable periods of time.

Fig. 6 is shown for the purpose of indicating how proficiently the first pilot subject executed the different tasks required of him. As in the case of the individual task proficiency curves that we have seen for the nonpilot subject, the vigilance task appears most adversely affected by the sustained work required of this subject. Interestingly enough, this particular subject did quite poorly on his radar reconnaissance task during his preflight training. At the end of his simulated flight, this subject remarked, during his debriefing, that he "really got with the radar reconnaissance task" throughout his flight. His apparent success which could only be attained by atypical or disproportionate time-sharing was at the expense, however, of his vigilance task. The more typical differential decline is illustrated by Fig. 7. Here, decrement in the vigilance task is not so great as in the graph just observed, and the proficiency with which the radar reconnaissance task is executed exhibits the usually observed fluctuations.

Before concluding with the presentation of results, one more graph should be examined. Fig. 8 is presented for the purpose of illustrating why, in appraising human behavior, several pertinent indexes are required. Note this first build-up in the partial pressure of CO_2

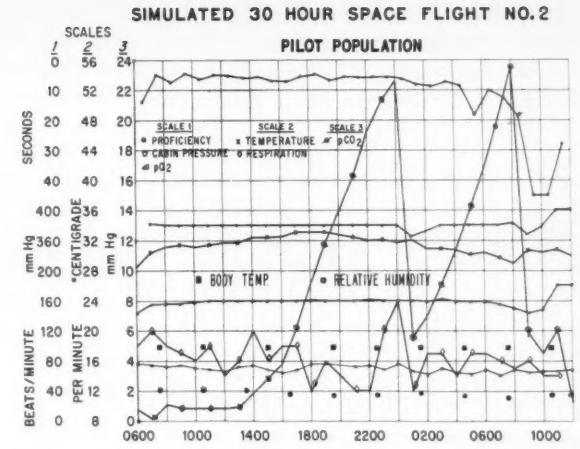

Fig. 8. Behavioral and environmental parameters evaluated during flight.

and the consequent effect upon respiration rate. Now let us examine what changes in proficiency might have been occasioned by such a substantial increment in pCO_2. The proficiency curve reveals no change whatsoever. The conclusion to be drawn, then, is that while a build-up of pCO_2 to about 23-mm. Hg pressure did produce the expected physiological changes, concommitant adverse change did not occur in the case of operator reliability.

Conclusions

The more general conclusions permitted by the data presented can be expressed in the form of cautionary considerations for manned space flight in a weapons system. Thus, under conditions somewhat similar to those of these investigations:

(1) Human reliability cannot be extended much beyond 20 consecutive hours.

(2) Careful attention must be given to circadian periodicity, specifically, the relationships between phase, period of operation, and local time.

(3) Reducing the vigilance loading imposed upon the human operator will have the effect of greatly increasing the reliability of this particular component.

Proceedings Available

The National Midwestern Meeting—Weapons System Management Proceedings (November 7, 8, 1957) contains all ***unclassified*** papers presented at the meeting.

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"Demands made on flight system for both manned and automatic flight . . . have resulted in a certain amount of necessary complexity. The pilot . . . is expected to improve materially flight safety and capsule system reliability."

Mercury Capsule and Its Flight Systems

Maxime A. Faget, MIAS, and Robert O. Piland

NASA Space Task Group (Langley)

PRELIMINARY DESIGN work and development testing on manned, ballistic capsules has been under way for a period of roughly 2 years. For the past year, the McDonnell Aircraft Corporation and National Aeronautics and Space Administration have been concerned with the detailed design and the development testing of the Mercury capsule. The purpose of this paper is to give a fairly detailed description of the capsule and its various on-board systems.

Objectives, Principles, and Methods

Before considering the Mercury capsule, it would be worth while to review the basis upon which the Mercury project was started. This is done in Table 1 which shows a checklist that has been in use since the initiation of the project. The basic objectives of Project Mercury are orbital flight and recovery of a manned vehicle and the studying of man's capabilities in the environment of the flight. The basic principles followed in getting the project under way were to use the simplest and most reliable approach, to keep new developments to a minimum, and to base the flight-test program on a progressive build-up of tests. The method adopted to carry this out was to use a ballistic re-entry vehicle, an existing ICBM booster for propulsion, retrorockets to initiate descent from orbit, and parachutes as a landing system. Finally, it was decided to provide complete escape capability during the boosted portion of the flight since it was recognized that the boosters would not be completely reliable.

Design Environment and Requirements

Although the Mercury capsule is based on the simple ballistic re-entry approach, one need only consider the extreme flight environment and the mission requirements to perceive that the design of the capsule and the various on-board flight systems involves a certain amount of complexity. These primary design considerations are listed in Table 2. During the flight, the capsule first must undergo the noise and vibration associated with large rocket-powered boosters and then must be able to exist for an extended period of time orbiting in space, including the retrorocket firing period. The re-entry flight involves a combination of heating rates and duration which is unique and quite severe. The return from orbit includes a wide spectrum of flight speeds and altitudes, a period of parachute descent and finally impact. Subsequent to landing, the capsule must continue to remain operative and aid recovery forces in the pickup. This final environmental condition will most likely be afloat on the high seas; however, the conditions following ground impact must also be considered.

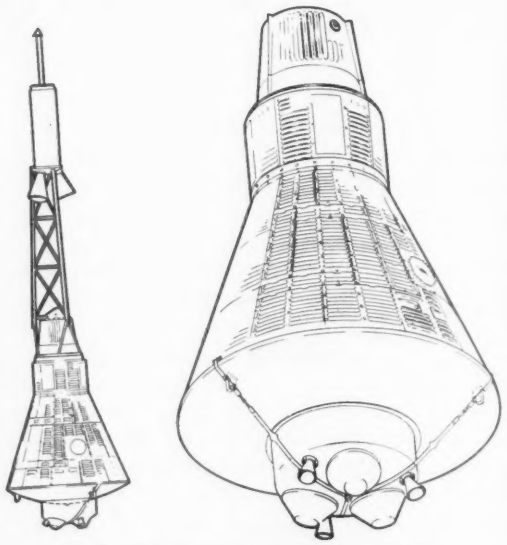

Fig. 1. Capsule and escape system configuration.

Table 1. Project Mercury

Objectives
(1) Orbital flight and recovery
(2) Man's capabilities in environment
Basic principles
(1) Simplest and most reliable approach
(2) Minimum of new developments
(3) Progressive build-up of tests
Method
(1) Drag vehicle
(2) ICBM booster
(3) Retrorocket
(4) Parachute descent
(5) Escape system

Mr. Faget is Chief, Flight Systems Division, NASA Space Task Group. Prior to this appointment, he was Head of the Performance Branch of NASA Langley Research Center's Pilotless Aircraft Research Division. While at PARD, he specialized in the fields of rocketry, bomb ejection at high speeds, missile and satellite re-entry, and aircraft performance, writing numerous technical papers and representing the NASA on various missile project working groups. Mr. Faget recently received the 12th annual Arthur S. Flemming award for his original contribution in connection with Project Mercury. He is a member of the IAS (Hampton Roads Section), the ARS, and the Academy of Model Aeronautics.

Mr. Piland is Assistant Chief, Flight Systems Division, NASA Space Task Group. Prior to this appointment, he was a technical assistant to the President's Science Advisor. From 1947 to 1958, Mr. Piland was with the NASA Langley Research Center's Pilotless Aircraft Research Division where he was active in the development of hypersonic multistage research rockets and in their use to study missile re-entry and aerodynamic heating problems. In 1956, he was appointed Head of PARD's Heat Transfer Section.

While operating in the above-mentioned environment, the capsule must, of course, provide the astronaut with a livable environment. Excessive accelerations are to be avoided during boost, re-entry, and at impact. As previously mentioned, the capsule must have a complete escape capability during powered flight. It is desired that the capsule have communications capability with the ground stations during the whole flight profile. In addition to the other requirements, the capsule must operate as a fully automatic system for a number of flights before the pilot is introduced into the system; however, when the pilot does fly, it is desired to give the pilot capability for control of the flight. It might be remarked here that the pilot adds a great deal of reliability to the various flight systems and that the capsule reliability and safety are certainly greater when the pilot is aboard.

Capsule and Escape System Configuration

Fig. 1 shows the capsule and escape rocket configuration. The capsule re-enters with the blunt end forward. This end is protected by a heat shield made of fiberglass. On the afterbody, heat is dissipated by radiation. This portion of the capsule is covered with metal shingles made of cobalt alloy. These overlapping shingles are corrugated for stiffness and are about 0.010-in. thick. Underneath the outer structure is a pressure vessel made of two thicknesses of 0.010-in. titanium.

Also shown in this figure is the retro package. This retro package contains the three retrorocket motors and the three posigrade rocket motors. The posigrade motors, which are the smaller, are fired at burnout of the booster and are used to effect separation with a velocity increment of about 20 fps.

The retrograde motors, which are fired in sequence, provide a velocity increment of about 500 fps and are used to bring the capsule out of orbit. The firing of the retrograde motors is interlocked with an attitude gate of $\pm 16°$ from the desired retrograde attitude. If the capsule attitude drifts out of this gate, the firing sequence is terminated until the attitude is corrected, thereby preventing a disastrous expenditure of the remaining rockets.

The escape rocket is shown mounted on a tripod which in turn is connected to the capsule by a Marmon band. This rocket provides a large total impulse to provide rapidly an adequate separation distance in case of a booster failure. If the booster fails on the pad, the rocket will lift the capsule to an altitude sufficient to allow deployment of the parachute. During flight in the atmosphere, the capsule escape rocket has a sufficient thrust-to-drag margin to separate the capsule from the booster. By jettisoning the escape rocket and tower after Atlas staging, while the velocity is still relatively low, only a small penalty is paid for this rather heavy system.

Booster Escape Initiation

Table 3 outlines the methods by which escape from the booster can be initiated. Essentially, this can be done by the pilot, by the ground crew, or automatically by the booster itself. The pilot may initiate an escape by twisting his left-hand grip. The test conductor in the blockhouse can initiate an escape through a hard line to the booster. Also, an escape can be initiated through a command link after lift off. The booster itself automatically initiates an escape if trouble is sensed in any of the critical booster systems. Both the Atlas and Redstone boosters have abort-sensing systems. Both these systems are based on sensing the least number of quantities that will indicate all possible types of impending failure. Detailed analysis of past booster development problems show that the booster abort-sensing system will initiate an escape at least several seconds before a catastrophic failure.

Table 2. Design Environment and Requirements

Environment and conditions
Booster-powered flight
Extended orbital flight
Exit from orbit
Re-entry flight
Landing and impact
Postlanding
Requirements
Support human life
Avoid excessive accelerations
Escape capability
Maintain communications
Fully automatic system with pilot override

Table 3. Booster Escape Initiation

Capsule-pilot control
Booster-automatic failure sensing
Attitude and rate
Engine chamber pressure
Propellant tank pressure
Electrical power loss
Ground-test conductor control—hardware
flight monitor control—R.F. link

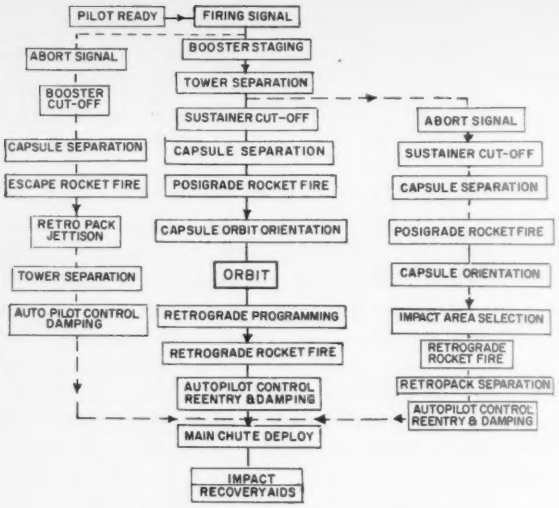

Fig. 2. Mercury-Atlas mission sequence.

Mercury-Atlas Mission Sequence

The flight events during the mission are controlled by a sequencer in the capsule. Fig. 2 presents important flight events for the normal mission and the sequence of events that would take place in the case of an abort either before or after booster staging. The middle column of Fig. 2 indicates the sequence of events for a normal mission. The mission is initiated by a firing signal from the blockhouse, once the pilot has indicated his readiness for the mission by closing the switch which lights the pilot-ready light in the blockhouse. Shortly after booster staging, the escape tower is jettisoned since its high impulse is not required for escape outside the sensible atmosphere. When orbital velocity is attained and the sustainer is cut off, the posigrade rockets are fired accomplishing capsule separation. The capsule autopilot then controls the capsule attitude through a series of maneuvers terminating with re-entry after the retrorockets are fired. These will be discussed in detail in later sections. At 10,000 ft., the main parachute is deployed, and, upon impact, recovery aids are put into operation. The reserve parachute is used only in the event of main parachute failure.

The left-hand column of Fig. 2 shows the series of events which will occur when an abort is initiated prior to booster staging. This would be an abort employing the escape rocket. In the right-hand column is shown the sequence of events that would take place if the flight were aborted after booster staging, but prior to sustainer cutoff. In this type of abort, the impact area could extend over several thousand miles. Therefore, a desirable impact area is selected by range monitors, and the flight is controlled by the time at which the retrorockets are fired.

The events shown on this chart are only the major ones and represent only a small portion of the actual number of events. Sequencing is carried out electrically by a combination of timers, sensors, and barostats. The most important of these is the retrograde firing timer, which is called the satellite clock. This timer is preset prior to launching but may be corrected during orbit, through radio command by the range monitors or manually by the astronaut.

Capsule Internal Arrangement

The internal arrangement of the capsule is shown in Fig. 3. The pilot is supported in the capsule in such a manner that, when the capsule is in the orbital attitude, he is sitting upright facing aft. In his right hand is the three-axis side-arm controller used for attitude control. His left-hand grip is the abort-initiation switch. Directly in front of the pilot is the instrument panel and the periscope display.

Details on this and other equipment will be discussed in the remainder of the paper. With this layout, the pilot has about the same amount of room found in a typical fighter cockpit. To each side of the pilot are equipment bays. The main and reserve parachutes are stored in the cylindrical afterbody, and the two infrared horizon-scanner units are located in the truncated cone section at the very end of the capsule. Fig. 3 illustrates the large number of separate items needed aloft to carry out the Mercury mission.

Environmental Control System

Fig. 4 shows a schema of the environmental control system. This system is used to provide the pilot with a suitable atmosphere and to cool the various equipment in the capsule. There are two control loops—the cabin circuit and the suit circuit. The cabin circuit provides cabin cooling. The suit circuit not only cools the air but removes odors, CO_2, and H_2O, and replenishes the oxygen that the pilot has used. While aloft, the Mercury astronaut breathes a pure oxygen atmosphere at 5 psi. He wears a full pressure suit which remains deflated unless there is a pressure failure in the cabin, which is also kept at 5 psi. In the suit circuit, odors are removed by an activated charcoal bed; the CO_2 is removed with lithium hydroxide; the air is cooled in the heat exchanger. Downstream of the heat exchanger, water condensed from the air is caught with a vinyl sponge which is squeezed out periodically into a con-

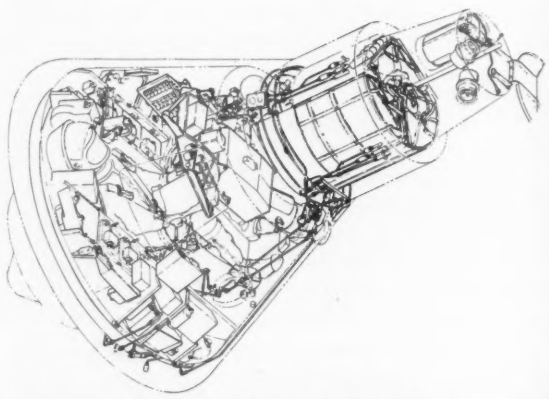

Fig. 3. Capsule internal arrangement.

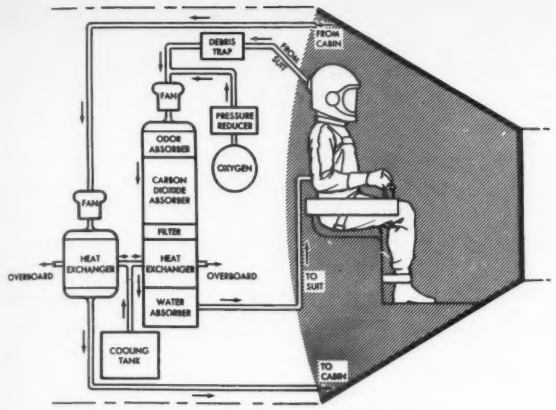

Fig. 4. The Mercury environmental control system.

densate container. Water is used as a coolant for both the suit and the cabin circuits.

Attitude Control System

Table 4 outlines the attitude control system which is used in the Project Mercury capsule. Attitude can be controlled either by a completely automatic system or by a manual system. H_2O_2 thrust chambers are used to provide correcting moments in both systems. There are two separate H_2O_2 systems provided, one for manual control and one for automatic control.

The autopilot used for automatic control consists of two attitude gyros, three rate gyros, and logic and programming circuits. During the flight, the vertical gyro is erected by the infrared horizon scanners. Erection is programed every 10 min. The vertical gyro is also constantly precessed in pitch to match capsule's rotation about the earth. The directional gyro is also erected at the same time as the vertical gyro. This is done essentially by aligning the gyro axis to eliminate apparent precession due to yaw error as the capsule rotates in pitch as it circles the earth.

H_2O_2 thrust chambers used in the automatic system are controlled by solenoid valves. In order to conserve fuel, two sets of thrust chambers were needed. For pitch and yaw, 24- and 1-lb. thrust units are used. For roll, 6- and 1-lb. units are used.

The manual control system has another complete set of thrust chambers which are throttleable. These are rated at 24 lbs. thrust for pitch and yaw and 6 lbs. thrust for roll. Each chamber can be operated through either a solenoid valve or a mechanical valve, depending on the method by which the pilot is using his control system. The primary method is a rate command system in which the pilot can, through his right-hand controller, command the rate of rotation in either of the three axes. In this system, the solenoid valves provide on-off control. Rate input is obtained from an additional set of rate gyros. In the event of an electrical failure, the pilot can elect to operate the same control system directly through mechanical linkages using the mechanical valves which are proportional. Analog studies have shown that control through the mechanical systems will be much more difficult, particularly during retrorocket firing when it is expected that large upsetting moments may develop. The pilot may, as a third alternative, control the thrust chambers of the automatic control system through electric switches on his controller. In this case, he would have neither proportional control nor rate input.

Automatic Control System Modes

Table 5 outlines the various modes in which the automatic control system will be operated during an orbital flight. First there is the orientation mode. Here either high- or low-torque thrust chambers will be used, depending on the magnitude of error. If there is only a small error of attitude and rate, low-torque thrust chambers are used. At greater errors, the high-torque thrust chambers are activated. The retrograde mode differs from the orientation mode in that only the high-torque thrust chambers are used. They are activated at the same error which would have activated a low-torque thrust chamber in the orientation mode. Thus the retrograde mode provides a much tighter control which is necessary to overcome the upsetting moments of the retrograde rockets.

In the orbit mode, a different type of control logic is used and only attitude sense is required. In this case, small calibrated pulses of thrust are used. This results in a long-period, lazy motion which will conserve the hydrogen peroxide propellant.

The damping mode is the same as the orientation mode, except that the attitude sense is cut out. During a normal mission, the automatic control system will be sequenced as follows. Immediately after separation, the automatic control system is in the damping mode for a period of about 5 sec. Then it is shifted to the orientation mode, while the capsule is rotated 180° in yaw and is pitched up 34° into the retrorocket firing attitude. The capsule remains in this attitude for a

Table 4. Attitude Control System

Automatic control system
Several modes of operation
Gyros erected by horizon scanners
Solenoid valve control
High- and low-thrust chambers
Manual control system
Rate command system (solenoid valves)
Direct mechanical linkage (proportional valves)
Pilot control of automatic system thrust chamber
H_2O_2 thrust chambers
Separate systems for manual and automatic control

Table 5. Automatic Control System Modes

Orientation mode
High- and low-torque thrust chambers
Attitude and rate sense
Retrograde mode
High-torque thrust chamber only
Attitude and rate sense
Orbit mode
Low-torque thrust chamber only
Attitude sense only
About 3-min. period
Damping mode
Low- and high-torque thrust chambers
Rate sense only

Table 6. Communication Systems

Two-way UHF voice
Two-way HF voice
Telemetry (UHF)
High frequency—may be keyed by pilot
Low frequency
Two command receivers
(Ground to capsule voice capability)
C-band radar
S-band radar
Recovery beacon—UHF/VHF
(SARAH/SEA-SAVE)
Emergency UHF/HF two-way voice

period of about 5 min. This is done so that the rockets may be fired quickly in the event it is determined by the range monitors that the capsule is not in a suitable orbit. At the end of this time, the capsule will be oriented to the orbital attitude, which is 14° nose up. This is the attitude which places the periscope axis normal to the earth.

After the capsule settles into the orbital attitude, the automatic control system is shifted to the orbit mode and remains in this mode until it is time for retrograde maneuver. At this time, the attitude control system shifts to the orientation mode and reorients the capsule to the retrograde attitude. It is then shifted to the retrograde mode while the retrograde rockets are fired. It is shifted again into the orientation mode and reorients the capsule to the re-entry attitude which is $1^1/_2°$ nose down. It remains in the orientation mode until entry into the atmosphere is sensed by a $^1/_{20}$th g acceleration switch. The automatic control system is then shifted into the damping mode and remains in the damping mode until the main parachute is deployed. At this time, the remaining hydrogen peroxide is jettisoned through the pitch and yaw thrust chambers.

Communication Systems

The various communication systems carried on the Mercury capsule are outlined in Table 6. Both UHF and HF frequencies are used for voice communications. These voice links are operated simultaneously. There are also two telemetry links, both in the UHF band, but one at a higher frequency than the other. As a backup to the voice communication, the high-frequency telemetry link may be keyed by the pilot. There are two identical command receivers, both operating on the same frequency carried on the Mercury capsule, through which three functions may be initiated from the ground —namely, resetting the retrotimer, firing the retrorockets, and aborting the mission. The command receivers can also receive voice communication, and this will be done simultaneously with the UHF and HF links when the capsule is in range of the command transmitter.

The Mercury network uses both C- and S-band radars and consequently both C- and S-band radar beacons are carried aboard the capsule. As an aid to search and recovery, a combination of the SARAH and SEA-SAVE beacon is carried on the capsule and is activated after the main parachute is deployed. In addition to the above equipment, there is a completely separate emergency two-way voice system consisting of UHF and HF transceivers.

While in orbit, all communication links, with the exception of the radar beacons, are multiplexed onto a common discone antenna located in the truncated cone at the rear of the capsule. This portion of the capsule, called the antenna section, is jettisoned at deployment of the parachute. At this time, the UHF links are transferred to a monopole antenna which is directly in back of the cylindrical portion of the capsule. Upon contact with the water, the parachute is jettisoned and an HF antenna is deployed by a helium-filled balloon.

Power Supply

The power supply system for the Mercury capsule is outlined in Table 7. The capsule uses electrical batteries as a power source. A.C. is produced by solid-state inverters. The battery power is provided in three batteries. There is a main battery and an auxiliary battery which is isolated from the main battery. These two batteries are backed up by a stand-by battery which is automatically switched in, in the event of failure of either of the other batteries. In a similar manner, there is a stand-by inverter which is automatically switched in, in the event of failure of either of the regular inverters.

Measurements by Instrumentation

Table 8 lists the various types of measurements which will be made during the orbital and ballistic flights of the capsule. These measurements will be telemetered to ground tracking stations and also recorded aboard the capsule by a tape recorder. The purpose of the majority of these measurements is self evident; however, it will be worth while to discuss a few of them. In the aeromedical area we are measuring the pilot's EKG, his respiration rate and depth, and his deep body temperature. On the unmanned flights, the voice communication system will be evaluated by transmitting from the capsule previously tape-recorded conversation and at the same time recording on tape trial communications transmitted to the capsule's receiving equipment. Monitoring of the satellite clock which fires the retrorockets is a particularly critical piece of information which must be telemetered to the range stations. Inasmuch as it may be necessary to change the setting of the retrofiring time by radio command, it is necessary that the ground stations have the capability of monitoring the performance of the satellite clock.

Table 7. Power Supply

Main battery
Three 1,500 watt-hour units
Auxiliary and recovery battery
One 1,500 watt-hour unit
Stand-by battery
Two 1,500 watt-hour units
Inverters—a.c. power supply
One 250 va.
One 150 va.
Stand-by inverter
One 250 va.

Table 8. Measurements by Instrumentation

(1) Aeromedical data	(7) Temperatures
(2) Sequence of events	(8) Pressures
(3) Control events	(9) Accelerations
(4) Capsule attitude	(10) Sound level and vibration level
(5) Voice communications—evaluation	(11) Power supply
(6) Satellite clock—monitoring	

Table 9. Cameras and Recording

Cameras
16 mm.—Pilot, 8,520 frames
16 mm.—instrument panel, 17,040 frames
70 mm.—earth and sky, 560 frames
Tape recorder—8-hour duration
Cosmic ray film pack

Cameras and Recording

Table 9 outlines the cameras and on-board recording equipment used in the capsule. There are two 16-mm. cameras, which photograph the pilot and the instrument panel. In addition, there is a 70-mm. camera to photograph the horizon through one of the windows of the capsule. These cameras not only will film the view from the capsule, but will provide useful information on the status of the on-board equipment, the condition of the pilot, and the motions of the capsule during the mission. There is a multitrack tape recorder in the capsule which records various measurements made during the flight. In addition, there are several cosmic ray film packs located near the pilot's head. These emulsion packages will record intensity and the direction of cosmic rays encountered during the orbit.

Air Cushion for Impact Attenuation

In order to attenuate to an acceptable level the decelerations resulting from impact with the water or ground, the capsule will land on an air cushion. This air cushion is illustrated in Fig. 5. It is formed by a 4-ft. skirt made of rubberized fiberglass that connects the heat shield and the rest of the capsule. After the main parachute is deployed, the heat shield is released from the capsule and the bag fills with air. Upon impact, the air trapped between the heat shield and the capsule is vented through holes in the skirt, as well as portions of the capsule which are not completely air tight, thereby providing the desired cushioning effect.

Instrument Panel

Since the instrument panel provides a summation of many of the details previously mentioned, it will be used to conclude this paper. The panel is shown in Fig. 6. The controls and displays on this panel are grouped as to function. The group on the left side has various pilot controls such as those concerned with the attitude control system and the retrorockets. The two large handles are for decompression and repressurization. Decompression would be the method used for extinguishing a fire.

The next group is a sequencing display. This consists of a series of lights proper in sequence indicating whether the various functions occurred or did not occur at the proper time. The light will come on green if the function does indeed occur and red if there is some failure in the automatic functioning. The handle just to the left of the particular light is the pilot's control to override and correct the failure to function. The light at the very top is the abort light which comes on in the event an abort is initiated. If the abort does not occur, the pilot can abort using his left-hand grip. The switch immediately under the abort light is the pilot's ready switch. This switch is used prior to launch to light up a ready light on the test conductor's panel in the blockhouse.

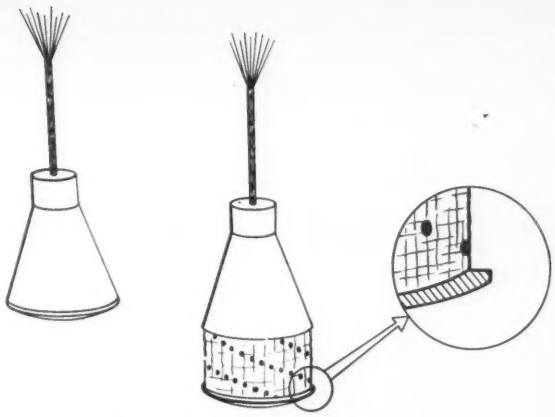

Fig. 5. Air cushion for impact attenuation.

The next series of dials are flight instrumentation. These read acceleration, rate of descent, altitude, and the fuel supply in the H_2O_2 tanks. The top center of the panel is used for attitude display. This combination display shows rate and attitude in pitch, roll, and yaw. The rate display is in the center, surrounded by the attitude displays consisting of three dials. This particular display for attitude control was arrived at after a number of simulation flights were made with various types of displays. The pilot's control of attitude will be aided by the periscope which is located in the center and below the instrument panel and a window which is located directly above the panel. The pilot will be able to see the horizon in back of the capsule through this window in both the normal orbital attitude of 14°, as well as the retrofiring attitude of 34°.

(*Continued on page 58*)

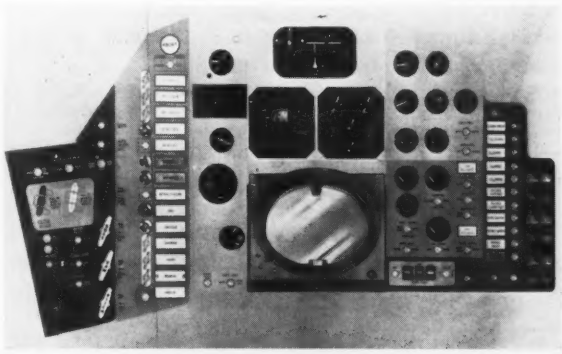

Fig. 6. Pilot's panel.

"In order to lower core costs, and for other reasons, several companies are now designing pebble bed systems for commercial power production and breeding."

Pebble Bed Nuclear Reactors

for Space Vehicle Propulsion

Myron M. Levoy and John J. Newgard, Thiokol Chemical Corporation

IT APPEARS FEASIBLE to utilize a pebble bed nuclear reactor for space vehicle propulsion, within certain limitations. A typical nuclear engine will be considered and the limitations discussed.

Background

Nuclear rockets have been described in the open literature for both terrestrial boost and space missions.[1–6] In the work to date, those reactors which have been seriously considered utilize reactor configurations of parallel plates, rods, or solid cylinders containing parallel cooling channels. In order that the coolant pressure drop be held to reasonable values, such configurations are necessary for the high propellant flows required in first- or second-stage boost rockets. For example, with a hydrogen propellant flow of 960 lbs./sec., a pressure drop across the core of about 700 psi will occur in a typical engine using parallel plate fuel elements in the reactor core; for the same engine with a pebble bed reactor core, the pressure drop is about 64,000 psi or 100 times greater. These pressures obviously are prohibitive and consequently parallel plates, rods, or the like, must be used. However, such core fuel elements are expensive to fabricate compared to pellets, and the placement of such fuel elements in the reactor, with narrow limits on orientation and spacing, leads to high costs of core structural supports as well. In order to lower core costs, and for other reasons, several companies are now designing pebble bed systems for commercial power production and breeding.[7–9]

Propulsion Requirements

In space vehicle propulsion, lower vehicle gross weights and lower acceleration requirements permit use of pebble bed reactors. The National Aeronautics and Space Administration has predicted a range of payload weights which may be launched into a 300 n.m. orbit for the next 10 years between 20,000 and 150,000 lbs., the former via a Juno V and the latter via Nova. The nuclear space vehicles to be discussed are assumed to be the payload of the boost rockets, in this case. Therefore, the 20 to 150,000 lb. payload range represents a space vehicle gross weight range. Also, for typical space missions (i.e., a Mars probe) it has been shown that initial accelerations from a 300-mile earth orbit may be as low as 0.2 to 0.4g with negligible performance loss.[10] With these limits, for a typical 5 ft. (right cylinder) reactor size and an I_s of 900 sec., a range of hydrogen propellant flows from 9 to 70 lbs./sec. would suffice for nuclear space vehicle requirements for the next ten years.

Fig. 1 shows the relationship of inlet pressure, flow rate, and pressure drop for a typical 5 ft. dia. by 5 ft. long right cylindrical reactor core with a fractional void of 0.39 using hydrogen propellant at an I_s of 900 sec. in vacuum. It may be seen that flows up to about 20 lbs./sec. are feasible with maximum inlet pressures of 900 or 1,000 psia. Such pressures are in the upper range of conventional chemical space vehicle design. (Ultimately, it will be necessary to compare the cost of pressure vessel fabrication and the cost of launching the increased pressure vessel weight into orbit for pebble bed reactors with inlet pressures of 300 to 900 psia and the

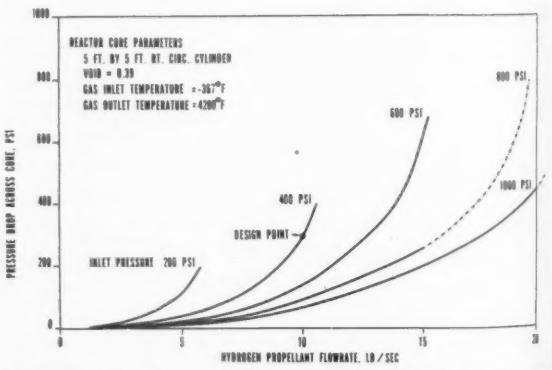

Fig. 1. Variation of pressure drop with propellant flow for a reactor for space vehicle propulsion.

The authors wish to thank Robert Behnke and David Wilson for their contributions to the preparation of this paper.

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Mr. Newgard, as a Fellow of the Mellon Institute, University of Pittsburgh, engaged in studies of electroluminescence and photoconductivity, and radiation damage to metals and alloys. He then carried out studies in reactor design and analysis at Westinghouse and engaged in the study of gas and liquid phase propellant interaction in rockets at the U.S. Naval Aeronautics Rocket Laboratory. He carried out nuclear and engineering analysis of aircraft nuclear power plants at Pratt & Whitney. Since 1956 he has been engaged in the analysis and design of nuclear rockets at the Reaction Motors Division of Thiokol.

comparable costs for flat plate reactors with inlet pressures of 100 to 300 psia and then to balance this against reduced costs of pebble bed core and pebble bed reflector.)

For flows greater than 15 to 20 lbs./sec., somewhat larger cores may be feasible without excessive weight increases. Also, reduction in pressure drop for the same core size is possible by increasing the void from 0.39 (randomly packed spheres) to 0.48 (cubic array), this latter at the expense of a higher concentration and inventory of uranium and increased core construction cost. Since nuclear space vehicles do not become truly competitive with high energy chemical rockets (for example: lox-hydrogen) below space vehicle gross weights of about 40,000 lbs.,[10] designs for high gross weights and higher propellant flows will be considered in a future paper. For the present, a design has been chosen for a space vehicle which could conceivably be launched and tested in space within the next five years. The design point is indicated in Fig. 1 and Table 1.

A schematic of the overall rocket system is presented in Fig. 2.[2] Liquid hydrogen at 37°R. is stored in insulated tanks. As a possible feed scheme, pressurized helium passing through flow regulators and heaters forces hydrogen from the tank to the propellant turbopump. The pump, which may be a single-stage centrifugal type, increases the pressure from about 30 psia to 450 psia. From the turbopump, the hydrogen flows through control valves (not shown) to the distribution plenum at the nozzle exhaust. It then flows back through regenerative cooling passages which constitute the nozzle and reactor chamber. The hydrogen passes into the reactor entry plenum and flows through the end reflector. At the exit of the end reflector, the pressure is about 400 psia. The hydrogen then flows down the reactor core where its temperature is raised to about 4,000°F. while the pressure drops to 100 psia due to the internal drag and turbulence. The hot gas is then ejected through a convergent-divergent nozzle.

A small fraction of the gas flow passes through the lateral reflector and exits at about 1,500°F. and 150 psia. This gas is ducted to the turbine of the turbopump and then exhausted for thrust recovery or vector control.

Reactor Core

A more detailed schematic of the core is presented in Fig. 3. The reactor core is a right cylinder composed of graphite spheres impregnated with uranium (designated in Fig. 2 as C: UC_2). In this design, the core is divided into three cylindrical compartments by graphite liners for the purpose of improved hydrogen flow distribution, as discussed below.

The core is surrounded by a lateral neutron reflector of BeO spheres contained in a graphite casing, and also an end reflector of BeO spheres. Reactor control is attained by means of rotating drums in the reflector.[2,11] The drums consist of BeO surrounded by a stainless steel jacket. One-half of the outer surface contains boron as a neutron poison. Rotation of these drums (there are twelve in all) leads to power control via reflection of more or fewer thermal neutrons into the core. Full rotation of all drums can give a $\delta k/k$ of 0.03.[11] The drums are cooled internally and externally, and coolant channels along the borated surfaces remove the heat of the n,α reaction.

The entire core and reflector is supported from the hot end by a graphite lattice structure and a tungsten retention screen which seats on graphite load-carrying members as shown. These members are tied into the nozzle wall which, in turn, is backed up by a thrust ring tied to the rocket skin. The interlocked graphite lattice structure can be several feet in depth, and the graphite load-carrying members could be beams spanning the nozzle entry, also several feet in depth. Gra-

Table 1. Design Parameters for a Typical Pebble Bed Reactor Space Vehicle

Vehicle gross weight, 33,300 lbs.
Propellant weight, 11,000 lbs.
Payload weight, 5,800 lbs.
Reactor core and reflector weight, 12,000 lbs.
Structures, shielding, pump, nozzle weight, 4,000 lbs.
Tankage weight, 500 lbs.
Propellant flow rate, 10 lbs./sec.
Specific impulse, 900 sec. (in vacuum) Ideal
Thrust, 9,000 lbs.
Initial acceleration, 0.3g
Reactor core size, 5 ft. by 5 ft. right cylinder
Reactor core void, 0.39
Fuel elements, Uranium-impregnated graphite pellets, 3 to 0.7 in. in diameter
Reflector thickness, 6 in. (BeO pellets of mixed sizes)
Reflector void fraction, 0.30
Critical mass 11.4 kg.
Hydrogen pressure and temperature at core and reflector inlet, 400 psia; −367°F.
Hydrogen pressure and temperature at core outlet, 100 psia; 4,200°F.
Hydrogen pressure and temperature at reflector outlet, 150 psia; 1,500°F.
Vehicle mission, 300 n.m. Earth orbit to Mars probe; Δv = 12,000 ft./sec. neglecting guidance; Hohmann minimum energy transfer ellipse

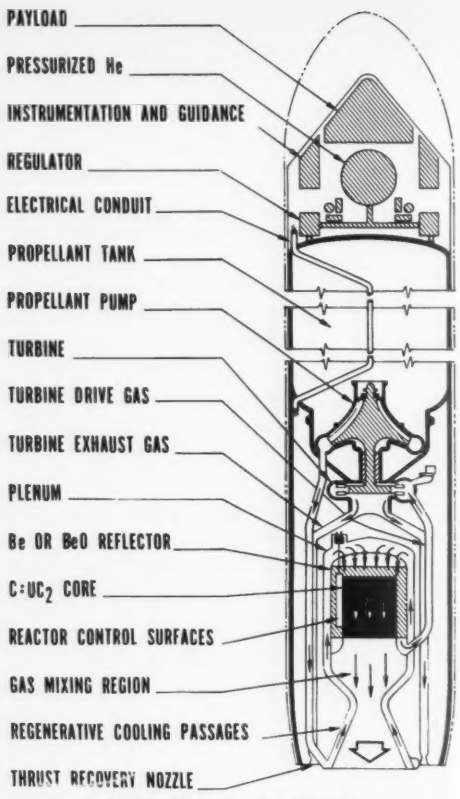

Fig. 2. Nuclear rocket schematic.

phite has been chosen in this application for its relatively excellent strength at temperatures in the 4,000°F. to 4,500°F. range. A detailed stress analysis is in progress to determine the feasibility of this support concept. It should be noted that retention screens are also used at the gas exit ports of the reflector.

The present design utilizes a pressure shell and nozzle of parallel tubes of nickel, Inconel X, or a stainless steel shaped to the proper core-nozzle profile. The tubes are flattened to permit exit ports from the reflector to pierce the wall. This flattening will pinch the upward flow of regenerative hydrogen creating additional pressure losses but may lead to easier fabrication of the ports. At the core support region, the tubes will be backed up by a cooled stainless steel support liner. (The load on the support structure of the reactor for a typical design is 130,000 lbs. for a 10*g* maximum acceleration assumed in boosting the space vehicle into orbit. Internal drag forces occur only after the boost is completed, when the vehicle acceleration is in the range of 0.03 to several *g*.)

The core has been compartmented for better flow distribution and a flatter gas temperature profile at the exit.[7] Due to flux buckling in a homogeneously fueled core, there is an increasing power density at the core center; consequently, flow will tend to channel toward the outer periphery of the core. To prevent this, differential radial uranium loading would be required to flatten the power profile. (However, power flattening must not be achieved at the expense of the ability of the reflector drums to provide the reasonably large reactivity changes anticipated, which might average 0.5 per cent in $\delta k/k$ per drum.) Also, flow in each compartment would be "orificed" by means of the end reflector—i.e., the BeO sphere sizes would be appropriately varied in each compartment to permit greater flows through the high power regions.

The same technique would be used to reduce the flow through the lateral reflector to the required value (about 5 per cent of the total flow). In order to maintain a high ratio of solid to total volume in the reflector, mixed sphere sizes will be used so that 30 per cent of the spheres will have sphere diameters one-fifth that of the remaining 70 per cent. In this way, by properly choosing the diameter of the spheres (while maintaining the 1:5 ratio), the flow rate through the reflector may be fixed at the design value.[7,12]

Fig. 4 shows the variation of critical mass of the reactor with reflector thickness and reflector void fraction for a 5 ft. by 5 ft. right cylindrical core of uranium loaded graphite pellets and 40 per cent void fraction in the core. In order to minimize engine weight, it is desirable to have as thin a reflector as possible compatible with a low uranium inventory, as shown in Fig. 4, and a controllable reactor—that is, one with a reasonably large average neutron lifetime. In prior work with flat plate element cores and solid BeO reflectors with cooling holes, it was found that a 6-in. reflector with 10 per cent void provided a satisfactory design.[2,11] [Reductions in reflector thickness below 6 in. are possible. It is interesting to note that smaller reflector thicknesses (below 6 inches) considerably reduce the reactivity perturbing effect of hydrogen density changes by shifting the neutron spectrum further into the epithermal region.[11] This reduction in perturbation may warrant sacrifices in maximum inventory, controllability, and drum excess reactivity control if experiments prove the perturbation to be severe, since in the highly reflected case (6 in. or more) this might cause the reactor to go prompt critical.] Such low voids are

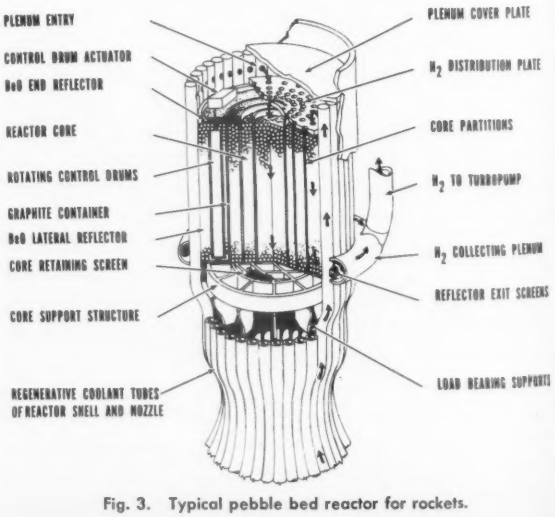

Fig. 3. Typical pebble bed reactor for rockets.

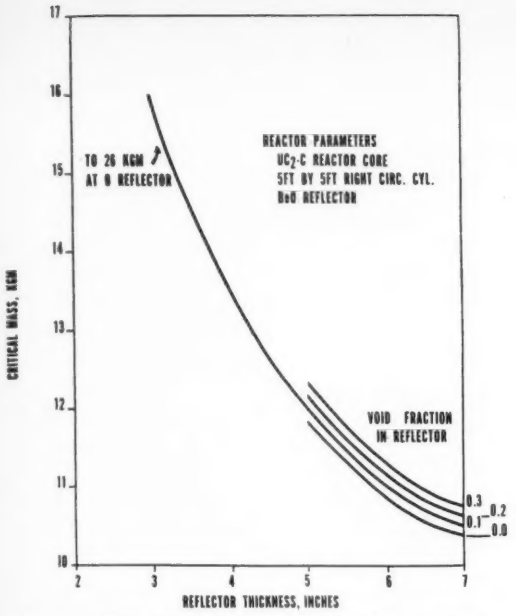

Fig. 4. Critical mass of reactors for space vehicle propulsion.

virtually impossible with pellet beds that may be reasonably fabricated since the filling of voids with smaller pellets results in new voids requiring still smaller pellets, ad infinitum. Therefore, the dual pellet size with 1:5 dia. ratio previously mentioned was used. The resulting 30 per cent void may be compensated by an increase in critical mass of 0.3 kg. The cost of this additional U-235 would be relatively negligible. The savings in reflector fabrication and structures cost is believed to be at least an order of magnitude greater than this.

From Fig. 4, it can be seen that, alternately, compensation can be achieved by increasing the reflector thickness to 6.6 in. In this case however, the cost of boosting the increased weight (450 lbs.) into a 300 n.m. orbit would be on the order of $250,000.

In order to attain a relatively low pressure drop of propellant through the reactor core by maximizing pellet diameter, the pellet diameters must be varied in the axial direction as indicated in Fig. 5, resulting in the axial pressure profile of Fig. 6. In actual practice, the pellet diameters might be stepped in three or more groups as indicated in Fig. 5. In fact, a smaller pellet diameter may be necessary in the first group at the cold end of the reactor to reduce the pellet-diameter-to-effective-bed-diameter ratio and hence prevent excessive wall channelling and large average void fractions due to gaps along the walls.

To fix pellet diameter at the largest permissible value at any point in the core, both temperature and thermal stress limits must be observed. The thermal stress was held to 70 per cent of the reported tensile strengths,[13] and maximum pellet center temperature was limited to 4,500°F. The resulting maximum and average pellet temperatures are shown in Fig. 7. From this, it may be seen that the thermal stress limit (at the sphere surface) was controlling for the first half of the reactor length, while the temperature limit controlled for the remainder. This pattern of temperature-stress limitations appears to hold for all reactors considered, including flat plate cores for high flow boost vehicles; the point where maximum temperature starts controlling shifts somewhat for different cases, however.

Conclusions

Once a design is chosen, such as the one suggested in this paper, a number of corrections must be applied to

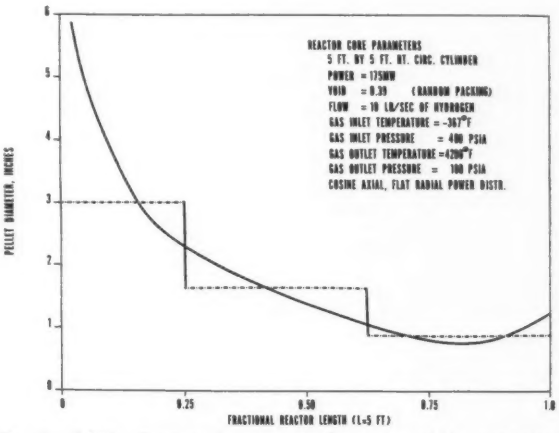
PELLET DIAMETER, INCHES
FRACTIONAL REACTOR LENGTH (L=5 FT)
REACTOR CORE PARAMETERS
5 FT. BY 5 FT. RT. CIRC. CYLINDER
POWER = 175MW
VOID = 0.39 (RANDOM PACKING)
FLOW = 10 LB/SEC OF HYDROGEN
GAS INLET TEMPERATURE = -367°F
GAS INLET PRESSURE = 400 PSIA
GAS OUTLET TEMPERATURE = 4200°F
GAS OUTLET PRESSURE = 100 PSIA
COSINE AXIAL, FLAT RADIAL POWER DISTR.

Fig. 5. Pebble diameters in a reactor for space vehicle propulsion.

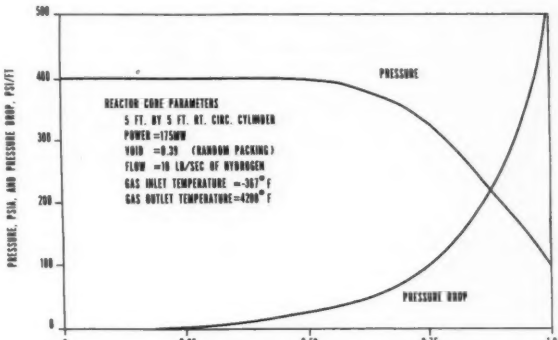
PRESSURE, PSIA, AND PRESSURE DROP, PSI/FT
FRACTIONAL REACTOR LENGTH (L = 5 FT)
PRESSURE
PRESSURE DROP
REACTOR CORE PARAMETERS
5 FT. BY 5 FT. RT. CIRC. CYLINDER
POWER=175MW
VOID =0.39 (RANDOM PACKING)
FLOW =10 LB/SEC OF HYDROGEN
GAS INLET TEMPERATURE =-367° F
GAS OUTLET TEMPERATURE=4200° F

Fig. 6. Axial pressure profile in a reactor for space vehicle propulsion.

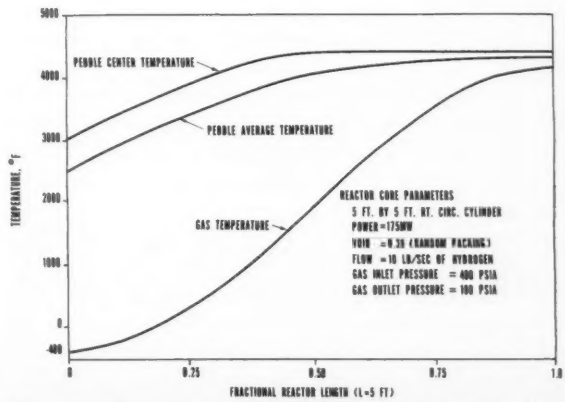
TEMPERATURE, °F
FRACTIONAL REACTOR LENGTH (L=5 FT)
PEBBLE CENTER TEMPERATURE
PEBBLE AVERAGE TEMPERATURE
GAS TEMPERATURE
REACTOR CORE PARAMETERS
5 FT. BY 5 FT. RT. CIRC. CYLINDER
POWER=175MW
VOID =0.39 (RANDOM PACKING)
FLOW =10 LB/SEC OF HYDROGEN
GAS INLET PRESSURE = 400 PSIA
GAS OUTLET PRESSURE = 100 PSIA

Fig. 7. Axial temperature profile in a reactor for space vehicle propulsion.

the first order results for a nonpartitioned core of Figs. 5–7. Summarizing from all of the above, the corrections include: (a) orificing via end reflector pellets or orifices, (b) corrections for radial power variation and for a more accurate axial power profile than the cosine distribution used at present, (c) corrections for discrete groups of pellet sizes axially rather than a continuum, (d) inlet and exit contraction and expansion losses and support screen pressure drop.

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✦ ✦ ✦

Ground Effect Machine (Continued from page 36)

one requiring more understanding. Thoughts on this subject presented here require, as far as the authors are concerned, additional confirmation and study to understand thoroughly the rather complex three-dimensional flow about the machine and the effect of the sink on this flow.

It seems evident that the hovering performance of the machine is in reasonable agreement with simple momentum theory. In this respect it should be pointed out that slot velocities are low (between 55 and 60 ft./sec.).

It also seems reasonable from results presented that there is good agreement between the shape of the model augmentation ratio curve and that of the full-scale machine.

✦ ✦ ✦

Mercury Capsule (Continued from page 53)

The periscope provides the pilot with a view of the earth beneath the capsule. By proper location of the earth's image in the periscope, he can control the attitude.

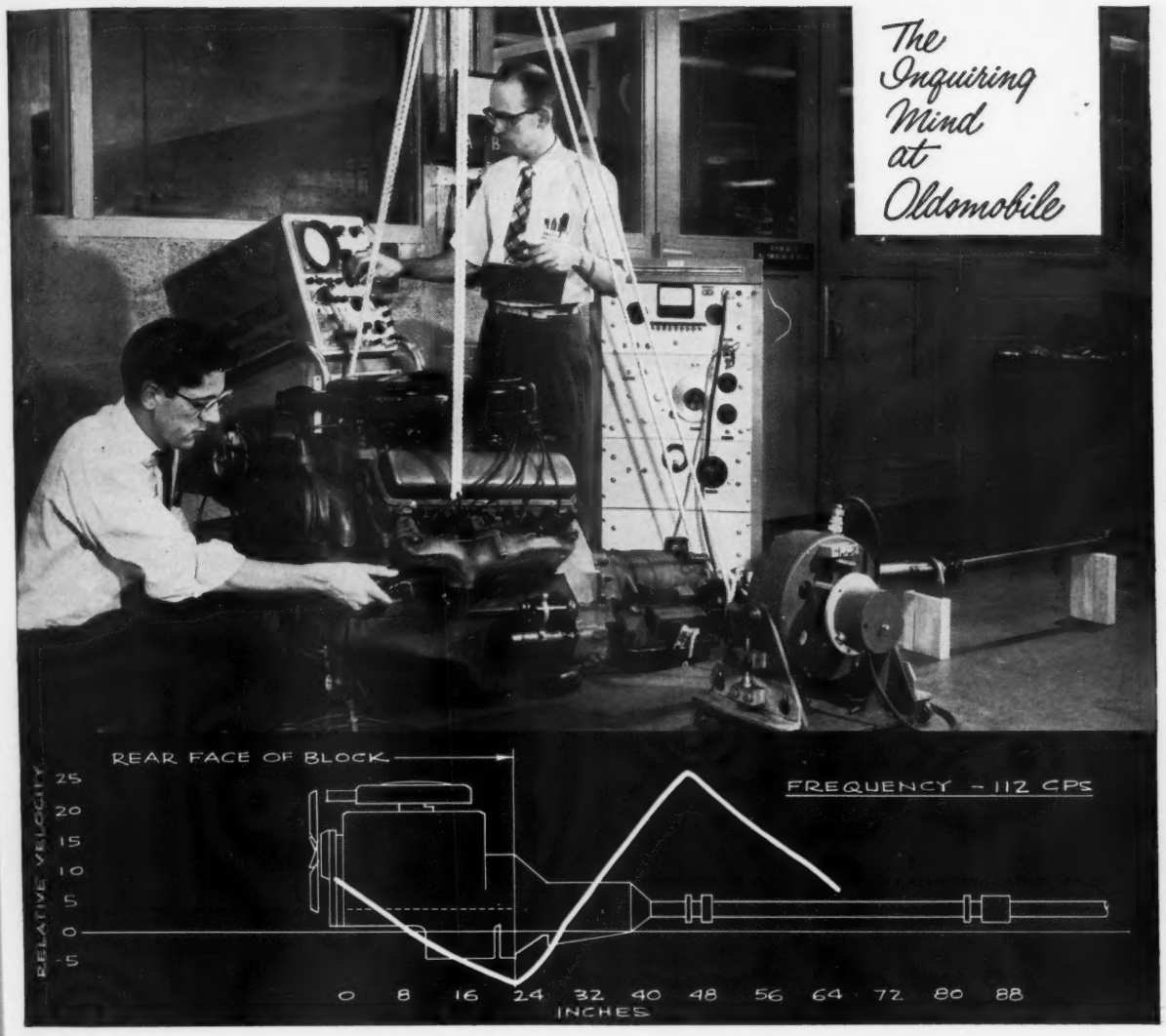
The instrument in the left center is a dead-reckoning type of device which consists of a small-scale model of the earth, clock-driven to rotate in time with the orbit. On the right center is the satellite clock, which in addition to firing the retrorockets indicates time of day, the lapsed time since launch, and time-to-go for retrorocket firing. The pilot is provided with an additional time-to-go dial which he may set for any desired event and also a separate stop watch.

The environmental control system display is in the upper right-hand portion of the panel. This includes such things as cabin pressure and temperature, suit pressure and temperature, and partial pressure of O_2 and CO_2. Directly beneath this is the power panel which monitors the electrical power system, and at the bottom are the communication system controls.

Further to the right are a series of warning lights which will flash on in the event a system failure is sensed. To call the pilot's attention to the warning light, an audio alarm will come on simultaneously. The audio alarm may be switched off by separate switches for each type of failure. The warning lights, on the other hand, will stay on until the failure is corrected. A number of critical fuses are located at the extreme right of the panel.

Conclusions

The Mercury capsule, although quite simple in concept, must provide the capability for a very difficult mission. The demands made on the flight system for both manned and automatic flight with sufficient back-up and redundancy in critical subsystems have resulted in a certain amount of necessary complexity. The pilot can monitor all the critical flight functions and is expected to improve materially flight safety and capsule system reliability.



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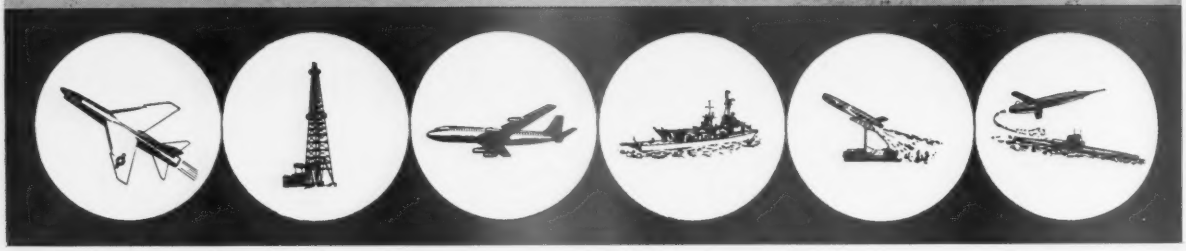

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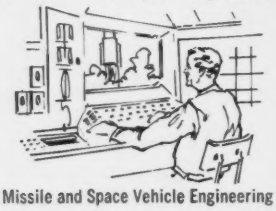

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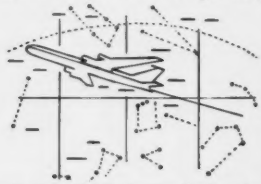

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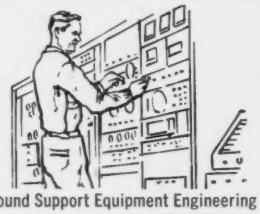

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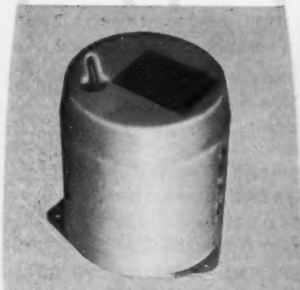

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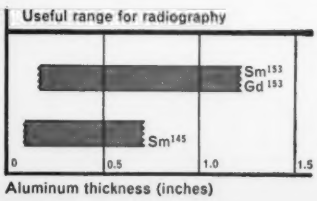

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Scientists at the General Motors Research Laboratories began three years ago to measure and re-evaluate the nuclear characteristics of these rare earth isotopes – their half-lives, photon emissions, thermal neutron cross sections.

Conclusion: the radioisotopes had attractive possibilities in industrial and medical radiography, emitting almost pure gamma rays or X-rays (photons) in the low energy range of 30 to 100 kev.

The transition from research to hardware came through two key developments. First, cermet pellets were fabricated using only a few milligrams of the rare earth oxides. Then the irradiated pellets were packaged in special bullet-size holders.

The resulting small, sealed radiographic sources are now being field and laboratory tested. Two excellent applications: "inside-out" checks of hollow shapes inaccessible to X-ray tubes, and radiography of thin steel sections and low density materials such as aluminum or human bone. For example, a recent medical milestone was a chest radiograph of a living person made with a Sm^{153} source. The portable exposure unit to shield the source weighed only 18 pounds.

This isotope radiography program is but one example of the work underway in GM Research's modern isotope laboratory – work that means, through science, "more and better things for more people."

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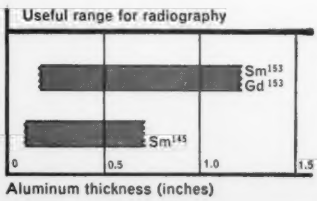

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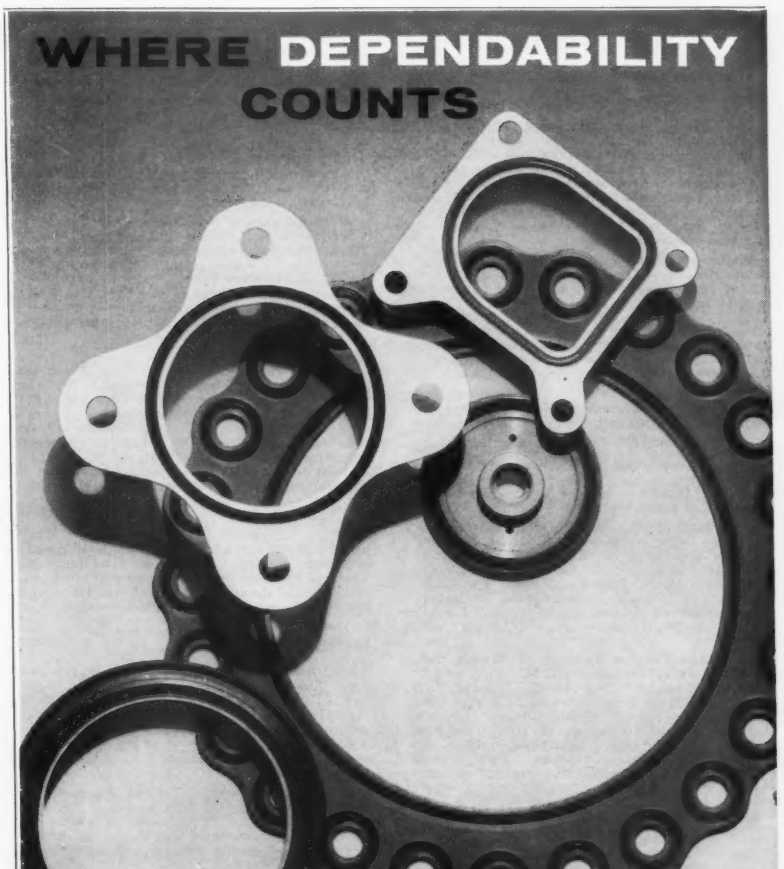

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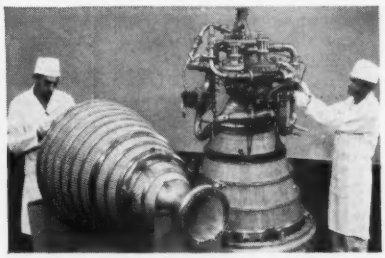

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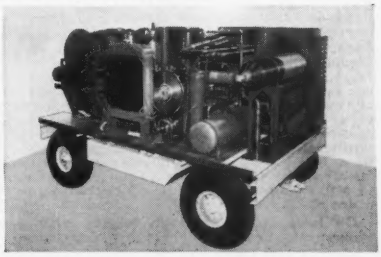

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The Occurrence of Damaging Hail at High Altitudes. H. S. Appleman and P. E. Lehr. *IAS 28th Annual Meeting, New York, Jan. 25–27, 1960, Paper 60-3.* Members, $0.50; nonmembers, $1.00. 6 pp. Review of the large-droplet theory of hail formation. The frequency of hail encounters is given as a function of altitude. The data are subdivided into low-altitude and high-altitude cases, and the relationship of hail frequency as a function of time of day and time of year is studied.

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A Basis for the Prediction of Severe Local Thunderstorms. D. C. House. *IAS 28th Annual Meeting, New York, Jan. 25–27, 1960, Paper 60-2.* Members, $0.50; nonmembers, $1.00. 11 pp. Discussion of the factors in the detection of stability and the stability trend, and of the prediction of the mechanism which will release the instability locally. An illustration of the prediction procedure is included.

Missile, Rocket, & Space Technology

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General Review of a Space Flight Programme Based on Blue Streak. G. K. C. Pardoe. *de Havilland Gazette*, Dec., 1959, pp. 172–175. Abridged.

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Results of Scientific Investigations Made by Soviet Sputniks and Cosmic Rockets. V. I. Krasovskii. (*ARS Annual Meeting, Wash., Nov. 17, 1959.*) *ARS J.*, Jan., 1960, pp. 27–33. Survey of geophysical data acquired by Soviet satellites and lunar probes.

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Basic Design Criteria for Moon Building. J. S. Rinehart. *Brit. Interpl. Soc. J.*, Sept.-Oct., 1959, pp. 126–129. Discussion of a proposed building for lunar use and the effects of environmental conditions on its design.

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Soviet Missiles. I—Liquid Rockets. A. J. Zaehringer. *Missile Des. & Devel.*, Jan., 1960, pp. 39, 40. Survey of Soviet liquid-fuel rockets.

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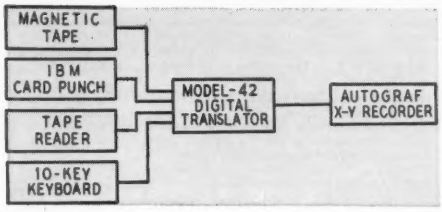

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Flight Testing the X-15. *Interavia*, Jan., 1960, pp. 57–60. Description of the airframe and the XLR-99 controllable rocket engine, and discussion of the flight test program up to November 5, 1959.

Hound Dog Designed for Off-the-Shelf Reliability. Irwin Stambler. *Space/Aeronautics*, Feb., 1960, pp. 54–58. Design study of North American GAM-77 Hound Dog air-to-surface missile. Aerodynamics, ground support equipment, and other special design aspects are discussed.

A Rocket for Manned Lunar Exploration. M. W. Rosen and F. C. Schwenk. (*10th Internatl. Astron. Fed. Congr., London, 1959.*) *IRE Trans., SET Ser.*, Dec., 1959, pp. 155–162. Presentation of a parametric study of vehicle size for the direct-flight manned lunar mission. The main parameter is the take-off thrust which is influenced by many factors, principally the propellants in the several stages and the flight trajectory. A close choice exists in the second stage where conventional and high-energy propellants are compared. The size of the final stage, and hence the entire vehicle, is governed mainly by the method of approach to the earth's surface, whether the approach is made at elliptic, parabolic, or hyperbolic velocities.

How Useful Are Low-Thrust Space Vehicles? Ernst Stuhlinger. *Astronautics*, Feb., 1960, pp. 24–26, 95–97. Consideration of the components of an ion propulsion system and the mechanics of its operation. It is pointed out that it promises usefulness in transporting great payloads. The possibility of its use as a vehicle to Mars and Venus is discussed.

Use of Energy Storage in Low Thrust Spaceflight. Morton Camac. (*Avco Everett Res. Lab. RR 36*, Oct., 1958.) *ARS J.*, Jan., 1960, pp. 54–63. USAF-sponsored analysis of flight plans for spacecraft operating at thrust levels that are much smaller than the local gravitational force. The thrust is limited by the average power generated.

Advantages of High-Thrust Space Vehicles. M. W. Hunter and J. M. Tschirgi. *Astronautics*, Feb., 1960, pp. 28, 29, 99–102. Comparison of high- and low-thrust propulsion systems in terms of payload efficiency and maximum velocity. The evaluation stresses the long operation time of low-thrust systems and the low reliability connected with this fact.

The Design and Operation of Propulsion Systems for Cruise-Type Missiles. S. Shrage. *SAE Natl. Aero. Meeting, New York, Mar. 31–Apr. 3, 1959, Preprint 54R.* 7 pp. Discussion of design criteria for reliability of engines operating within the atmosphere at speeds up to Mach 4. The engine, induction and exhaust systems, engine installation, and fuel system are examined.

On the Methods and Economics of Recovering Boosters for Orbital Vehicles. P. R. Shipps. *IAS 28th Annual Meeting, New York, Jan. 25–27, 1960, Paper 60–29.* Members, $0.50; nonmembers, $1.00. 15 pp. Discussion of four different two-stage booster systems: the built-up rocket, the "optimized" rocket, the semi-recoverable, and the highly recoverable boosters. Trajectory and operational differences, as well as system cost comparisons are given.

Solar Sail: Key to Interplanetary Voyaging? B. W. Powell. *Spaceflight*, Oct., 1959, pp. 116–118. Discussion of the physical principles and applications of a solar-sail vehicle. In such a vehicle, a parachute-type sail captures radiation pressure from the sun.

Solid Propellents in Spaceflight. *The Aeroplane & Astronautics*, Jan. 8, 1960, pp. 45–47. Discussion of the advantages of solid propellants, the use of solid propellants in the Vanguard third stage, and design details of a proposed three-stage solid-propellant rocket, called Envoy, that can be built more cheaply than the Scout rocket.

The Application of Solid Propellant Rocket Motors to Boost Space Vehicles. Giulio Panelli. *IAS 28th Annual Meeting, New York, Jan. 25–27, 1960, Paper 60-53.* Members, $0.50; nonmembers, $1.00. 11 pp. Comprehensive performance analysis showing the feasibility of solid-propellant first-stage boosters. Structural design, trajectory techniques, and propulsion design are examined.

Britain's Ballistic Research Vehicle. *The Aeroplane & Astronautics*, Dec. 4, 1959, pp. 567–571, cutaway drawing. Presentation of design, structural, control and stability, and propulsion characteristics of the Black Knight rocket. Description of ground equipment is included.

Hypersonics. *Flight*, Dec. 25, 1959, pp. 775–779. Summary of two papers by Metcalfe and Eggers on the aerodynamic requirements and the possible configurations for several types of vehicles such as skip, glide, and sustained flight vehicles and, in addition, anti-aircraft and anti-missile missiles.

A Preliminary Investigation of the Penetration of Slender Metal Rods in Thick Metal Targets. J. L. Summers and W. R. Niehaus. *U.S., NASA TN D-137*, Dec., 1959. 9 pp.

Performance Investigation of a Nonpumping Rocket-Ejector System for Altitude Simulation. Appendix—Ejector Theory; No Secondary Flow and Sufficiently Large Length-to-Diameter Ejector-Tube Ratios. Anthony Fortini. *U.S., NASA TN D-257*, Dec., 1959. 33 pp.

Some Problems of Providing for Scientific Research on Rockets. A. A. Blagonravov. (*ARS Annual Meeting, Wash., Nov. 17, 1959.*) *ARS J.*, Jan., 1960, pp. 22–27. Discussion of some particular solutions to instrumentation problems in Soviet rockets. These include the isolation of measuring instruments from the rocket carrier to eliminate disturbances caused by rocket motion, ejection and recovery of scientific apparatus, description of the heat control system used in Lunik III, and some problems resulting from the use of animals (principally dogs) for space investigation.

Fundamentals of Missile Instrumentation. J. R. Warren. *Western Av.*, Oct., 1959, pp. 24, 25. Discussion of some telemetering problems in the testing of missiles.

Cosmic-Ray Instrumentation in the First U. S. Earth Satellite. G. H. Ludwig. *Rev. Sci. Instr.*, Apr., 1959, pp. 223–229. Description of the instrumentation carried in the Explorer 1 to measure cosmic ray intensity, micro-meteorite impacts, and temperatures within the satellite.

Sergeant GSE Sets Pattern for IRBM Mobility. Victor de Biasi. *Space/Aeronautics*, Dec., 1959, pp. 55–58. Presentation of design features of complete ground support equipment for the Sergeant ballistic missile. Operation of equipment and the essentials of the automatic checkout system are discussed.

How Navy Will Monitor Polaris Underwater Firing. Philip Geddes. *Aircraft & Missiles*, Feb., 1960, pp. 22–25. Discussion of the planned ship-shore-submarine complex. The electronic system in the submarine and the use of a special camera are covered.

Space GSE Backs Atlas-Able System. *Western Av.*, Dec., 1959, pp. 44, 45, 54. Presentation of a work-schedule in the construction of the ground support equipment and classification of such equipment.

Lockheed Trims Polaris Vehicle's Weight. W. S. Reed. *Av. Week & Space Tech.*, Feb. 8, 1960, pp. 52, 55, 56, 59. Description of the underwater tests, combined systems tests, seagoing laboratory tests, and static firings used to perfect the fully-guided Polaris missile.

Role of Titan Support Equipment. *Western Av.*, Dec., 1959, pp. 20–22, 82. Description of the ground support equipment for the Titan. The missile handling equipment, control and checkout equipment, and the missile supply system are studied in detail.

Atlas ICBM Ground Support Goes Operational. E. T. Clare. *Western Av.*, Dec., 1959, pp. 26–28. Classification and discussion of the ground support equipment. The complexity of an operational base is illustrated in the discussion.

Cryogenics Applied to Missile Support. *Western Av.*, Dec., 1959, pp. 31, 32. Discussion of the use of ultra-low temperature oxygen and nitrogen in both the pre-operational and operational phases of missilery. Equipment for handling cryogenic liquids is also discussed.

Ground Support Ready for Polaris Fleet Ballistic Missile. R. T. Bumstead. *Western Av.*, Dec., 1959, pp. 36, 37, 75. Review and classification of ground handling equipment. The development flight test program is discussed.

How to Support Hound Dog Missiles. E. B. Price. *Western Av.*, Dec., 1959, pp. 38–40, 63, 64. Description of the ground support equipment of an air-to-surface missile. Areas of standardization are discussed, and a brief description of the Hound Dog is included.

Building Your Own Combined Environment Tester. O. B. Farley and J. B. Fellows. *Space/Aeronautics*, Feb., 1960, pp. 103, 104, 106–114 (ff.). Description of the construction, from commercially available parts, of a test fixture for simulating the combined missile environments produced during engine firing and the first seconds of flight.

Component Testing Makes Atlas Reliable. W. W. Holbrook. *Aircraft & Missiles*, Feb., 1960, pp. 56–59. Discussion of the test procedures and instrumentation used to check-out the Atlas liquid oxygen tank pressure regulators.

Propulsion Requirements of a Manned Lunar Mission. D. E. Serrill and H. J. McClellan. *IAS 28th Annual Meeting, New York, Jan. 25–27, 1960, Paper 60-30.* Members, $0.50; nonmembers, $1.00. 11 pp. Presentation of the advantages of high-energy large booster engines. The need for a throttleable landing engine and a greater reliability in engineering and design is pointed out.

RCA Takes New Approach to Missile & Satellite Detection; Synchronous Scanning Antenna System Proposed for Atlantic Range. G. W. Soderquist. *GSE*, Dec., 1959–Jan., 1960, pp. 59, 60, 62.

Na Gornoi Astronomicheskoi Stantsii. M. N. Gnevyshev. *AN SSSR Vestnik*, May, 1959, pp. 99, 100. In Russian. Brief discussion of optical measurements taken of the sodium cloud released by the Soviet cosmic rocket.

Na Stantsii Fotograficheskikh Nabliudenii. D. A. Rozhkovskii. *AN SSSR Vestnik*, May, 1959, pp. 95–98. In Russian. Description of the equipment used at a satellite tracking station in USSR, and discussion of some observations.

Astronomicheskie Nabliudeniia Iskusstvennykh Sputnikov Zemli. A. G. Masevich. *AN SSSR Vestnik*, May, 1959, pp. 85–94. In Russian. Discussion covering the astronomical observations of artificial earth satellites, equipment and methods used, various photographic techniques, and survey of some results, as well as the objectives of the IGY.

The Application of Radio Interferometry to Extraterrestrial Meteorology. M. J. E. Golay. *IRE Trans., SET Ser.*, Dec., 1959, pp. 186–193. Discussion of the interferometric link with reference to the transmit-receive problem and to the noise problem in a frequency tracking circuit. Several possible interferometric applications are listed and a table is presented in which an attempt is made at estimating the essential parameters in each system.

The 600-Foot Radio Telescope. E. F. McClain, Jr. *Sci. Am.*, Jan., 1960, pp. 45–51. Description of a telescope being built by the Navy in West Virginia, and discussion of the scientific knowledge to be gained from such an instrument.

Experimental Observation of Space Vehicles. R. Y. Miner. *ARMA Eng.*, Sept.-Oct., 1959, pp. 16–21. Survey of available data on visual and radio observation methods and the necessary equipment requirements.

Determination of Radiant Energy Requirements for Photographic Space Vehicle Tracking. T. P. Rona. *USAF MDC TN 59-31*, Nov., 1959. 13 pp. Analysis showing that for optical tracking in a clear atmosphere, signal-to-noise ratio is at least equal, and often superior to, radar communication. It is further shown that techniques for vehicle-borne flash sources are within the state of the art and, finally, that star background reference can be made available for increased absolute accuracy.

Infrared Tracking. R. W. Powell. *ARS J.*, Dec., 1959, pp. 973–980. 64 refs. Review of the state of the art of infrared tracking and range detection capability. The improvement of cell detection in larger wavelength range and the resultant higher scan speeds are examined. New optical materials and systems are treated, and the development of space filtering is discussed.

A Missile-Borne Transistor Flash Detector. F. R. Knott. *Gt. Brit., RAE TN G.W.520*, Aug., 1959. 29 pp. Description of a missile-borne flash detector to telemeter the time at which each flash occurred so that timing data of sufficient accuracy could be obtained from the telemetry record in the event of loss of information by the ground instrumentation.

TM-76 Mace Landing Mat Design. Kenneth Idomir. *Aero/Space Engrg.*, Feb., 1960, pp. 28–33. Description of a parachute recovery system with two pneumatic landing mats.

Effects of Water-Landing Impact on an Orbital Capsule from the Standpoint of Occupant Protection. H. G. Hatch, Jr. *U.S., NASA TN D-39*, Sept., 1959. 18 pp. Description of a series of tests on a cone-shaped capsule with a segment of a sphere at the bottom to determine the water-landing characteristics. It was found that an acceleration onset rate of approximately 25,000 g/sec. with an acceleration varying between 20g and 60g, depending upon the impact conditions, should be expected for an impact velocity of 30 ft./sec.

Economy and Techniques of Large Missile Booster Recovery. H. H. Koelle. *Western Av.*, Dec., 1959, pp. 46–49. Discussion of the factors influencing the cost of missile launching. Operational and cost parameters are enumerated, their relationship is given, and assumptions for the numerical examples are discussed. Numerous booster recovery systems are also mentioned.

Ballistics, Re-Entry

Analytical Estimates for Optimum Transfer Paths. H. Munick and R. McGill. *ARS J.*, Jan., 1960, pp. 120–122. Extension of Lawden's work concerning the minimization of characteristic velocity, or the amount of fuel consumed, using two impulses.

Re-Entry from Orbit. W. F. Hilton. *The Aeroplane & Astronautics*, Jan. 22, 1960, pp. 116–118. Abridged. Discussion of two types of re-entry vehicles, the problem of heat, and the best orbit for human spaceflight.

The Use of Rotors for the Landing and Re-Entry Braking of Manned Spacecraft. Ch. R. Haig, Jr. *IAS 28th Annual Meeting, New York, Jan. 25–27, 1960, Paper 60-17.* Members, $0.50; nonmembers, $1.00. 15 pp. Discussion of the rotor landing system concept and presentation of the re-entry rotor concept. The characteristics of the rotor are studied and the advantages of its use are summarized.

Guidance, Control, Stability

Flight Controls: A Look Into the Future. H. E. Arnzen. *Space/Aeronautics*, Feb., 1960, pp. 46–49. Analysis of future flight control sys-

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ACOUSTICS, SOUND, NOISE

NOISE PRODUCTION IN A TURBULENT BOUNDARY LAYER BY SMOOTH AND ROUGH SURFACES. E. J. Skudrzyk and G. P. Haddle. ASA J., Jan., 1960, pp. 19-34. 33 refs. Presentation of an attempt to predict the levels of the boundary-layer noise and the noise produced by the surface roughnesses as a function of the speed and the frequency. The fluctuations in pressure can be computed from those of the velocity by an equation similar to the standard Bernoulli equation, except that the numerical constant is different. Vortices pass along the receiving hydrophone; they represent pressure pulses that generate a constant power spectrum at low frequencies which decreases approximately inversely proportional to the cube of the frequency at higher frequencies. This information, in conjunction with the pressure equation, makes it possible to compute the power spectrum of the flow noise as a function of the frequency, the boundary-layer thickness, and the speed of the flow. The flow noise at greater speed and at higher frequencies appears to be predominantly generated by the surface roughnesses.

AERODYNAMICS, FLUID MECHANICS

Aerothermochemistry, Dissociation, Ablation

THE INFLUENCE OF GAS DISSOCIATION ON HEAT TRANSFER. Appendix I - VISCOSITY. Appendix II - PARAMETERS USED IN RECOVERY FACTOR COMPUTATIONS. W. J. Thievon, G. A. Sterbutzel, and J. L. Beal. USAF WADC TR 59-450, June, 1959. 141 pp. 15 refs. Investigation of the recovery factor and heat transfer rates for dissociating N_2O_4 gas under turbulent flow in a tube. The results show that the recovery factor based upon temperature has a consistent trend with composition and varies from 0.2 to 0.85. Recovery factors based on enthalpy show considerable scatter and are smaller than $Pr^{4/3}$. It is found that the heat transfer coefficients for the dissociating gas are many times higher than those obtained for the gas under frozen equilibrium conditions. For the situation in which heat flows from wall to stream, the Stanton numbers based on enthalpy are in agreement with a common equation for nondissociating gases, except that the ratio of enthalpy in the stream to that at the wall is introduced.

AN ANALYSIS OF ABLATION-SHIELD REQUIREMENTS FOR MANNED REENTRY VEHICLES. Appendix - FORMAL DEVELOPMENT OF THE DIFFERENTIAL EQUATIONS AND BOUNDARY CONDITIONS. Leonard Roberts. US, NASA TR R-62, 1960. 58 pp. 10 refs. Analysis of the problem of sublimation of material and accumulation of heat in an ablation shield. The results are applied to the re-entry of manned vehicles into the earth's atmosphere. The parameters which control the amount of sublimation and the temperature distribution within the ablation shield are determined and presented in a manner useful for engineering calculation. It is shown that the total mass loss from the shield during re-entry and the insulation requirements may be given very simply in terms of the maximum deceleration of the vehicle or the total re-entry time.

THE USE OF MODULATED ATOMIC-BEAM TECHNIQUES FOR THE STUDY OF SPACE-FLIGHT PROBLEMS. G. S. Holister, R. T. Brackmann, and W. L. Fite. (Conf. Phys. Chem. in Aerodynamics & Space Flight, Phila., Sept. 1-3, 1959.) Gen. Dynamics Corp, Gen. Atomic Div. GA-1024 (AFOSR TN 59-1033), Oct. 14, 1959. 17 pp. Application of modulated-atomic-beam techniques to investigate atom-surface interactions which affect drag on objects flying in atmospheres where the gas is dissociated - i.e., above 100 km. Two types of experiments are discussed. In the first, an incident beam impinges on a surface and the particles leaving the surface are examined with a mass spectrometer. By varying the incident beam and/or surface temperature, thermal accommodation coefficients are determined for a variety of surfaces and gases. In the second, the atomic

beam, which is monitored mass-spectrometically, is allowed to strike a surface placed on a torsion balance, and momentum transfer is measured directly. In these experiments, the atomic-beam apparatus is used as an atomic wind tunnel; when a hydrogen-atom beam from a furnace source operating at 3,000°K. is used, the case of a high-altitude satellite is fairly closely duplicated.

Aerothermodynamics

MASS TRANSFER COOLING EXPERIMENTS ON A HEMISPHERE AT M = 5. G. E. Anderson, C. J. Scott, and D. R. Elgin. U. Minn. Inst. Tech. RAL Res. Rep. 166 (AFOSR TN 59-1306), Aug., 1959. 26 pp. 16 refs. Description of studies made with a segmented porous hemisphere, designed and constructed to provide a constant temperature surface with helium mass transfer cooling. The variation of surface heat transfer with helium injection rate and with position on the hemisphere surface is measured. The data are presented along with available analytical results.

Boundary Layer

THE EFFECT OF CONTROLLED THREE-DIMENSIONAL ROUGHNESS ON BOUNDARY-LAYER TRANSITION AT SUPERSONIC SPEEDS. E. R. van Driest and W. D. McCauley. (IAS 27th Annual Meeting, New York, Jan. 26-29, 1959.) J. Aero/Space Sci., Apr., 1960, pp. 261-271, 303. USAF-supported presentation of test results indicating the following: (1) transition from laminar to turbulent flow induced by three-dimensional roughness elements begins when the double row of spiral vortices trailing each element contaminates and breaks down the surrounding field of vorticity; (2) transition appears rather suddenly, becoming more violent with increasing roughness height relative to the boundary-layer thickness; (3) after the breakdown of the vorticity field, the strength of the spiral vortices may still persist in the sublayer of the ensuing turbulent flow; (4) lateral spacing of roughness elements has little effect upon the initial breakdown (contamination) of the laminar flow, and (5) the trip Reynolds number Re_k varies as the position Reynolds number Re_{x_k} to the one-fourth power.

THE BOUNDARY LAYER NEAR THE STAGNATION POINT IN HYPERSONIC FLOW PAST A SPHERE. T. K. Herring. J. Fluid Mech., Feb., 1960, pp. 257-272. Analysis considering the region close to the stagnation point between the shock and the sphere that can be taken to be a steady laminar boundary layer. The solution consists in reducing the equations of motion to ordinary differential form by assuming forms of the flow variables which satisfy the boundary conditions, notably at the shock wave. Included are a selection of temperature and transverse velocity profiles across the boundary layer and several graphs relating such quantities as the shock stand-off distance and the skin-friction coefficient with Reynolds number. It is shown that the shock stand-off distance increases with increase in Reynolds number, whereas it is known that the boundary-layer thickness decreases. The skin friction coefficient is shown to be inversely proportional to a decreasing power of the Reynolds number when it is lower than order 10^3, but the indication is that it tends to the expected constant power of 1/2 when the Reynolds number is of order 10^4.

Flow of Fluids

D - STRÖMUNGSLEHRE. (GAMM Wissenschaftliche Jahrestagung, Hannover, May 19-23, 1959.) ZAMM, Sept.-Nov., 1959, pp. 428-453. 32 refs. In German. Partial Contents: Die Grenzschichtströmung in einer rechtwinkligen Ecke, Klaus Gersten. Zur Berechnung der Potentialströmung um beliebige Einzel- und Gitterprofile unter Verwendung der Elektroanalogie, M. Hackeschmidt. Über ein Randwertproblem aus der Aerodynamik eines Gitters, E. Meister. Über das Wandgesetz turbulenter Grenzschichten bei kompressiblen Strömungen, J. C. Rotta. Berechnung von symmetrischen Profilströmungen mit beschränkten Überschallbereichen, E. Schincke. Kugelsymmetrische Verdichtungsstösse mit Dissoziation und Ionisation, I. Teipel. Mathematische Fragen der transsonischen Gasdynamik, F. G. Tricomi. Verallgemeinerte ähnliche Lösungen bei dreidimensionalen Grenzschichten, W. Wuest. Symposium of papers covering the conversion of a given velocity distribution over a single profile or a cascade to cover a different state of flow; calculation of the boundary-layer flow across a rectangular corner; the relationship between the linear and nonlinear theories of flow with cavitation; calculation of the potential flow over single and cascade profiles by means of the electric analogy; certain boundary problems in the aerodynamic study of cascades; determination of errors in approximate solutions of boundary-layer differential equations; turbulent boundary layers in incompressible flow; symmetric profile flow of ideal compressible fluids; spherically symmetrical compression shocks with dissociation and ionization; mathematical problems in transonic gas dynamics; and generalized analogous solutions for three-dimensional boundary layers.

SPECIAL ISSUE: SEMINAIRE D'AEROTHERMIQUE DE LA FACULTE DES SCIENCES DE PARIS. France, Min. de l'Air NT 85, 1959. 170 pp. 112 refs. SDIT, 2 Av. Porte-d'Issy, Paris 15, Frs. 3,050. In French. Contents: Recherches Récentes dans le Domaine Aérodynamique des Gaz Raréfiés, L. Talbot. Structure de l'Onde de Choc, L. Talbot. L'Ecoulement de Couette dans un Gaz Raréfié, L. Talbot. Pressions sur des Cônes et des Plaques Planes Placés dans un Ecoulement Hypersonique, L. Talbot. La Couche Limite Laminaire à Trois Dimensions, E. A. Eichelbrenner. Individualisation de la Matière dans les Ecoulements, Charles Bory. Sur le Développement de la Détonation dans un Gaz; Analyse du Processus de Formation de l'Onde, A. K. Oppenheim and R. A. Stern. Ondes de Choc Produites dans les Tubes à Gaz par Décharges de Condensateurs, Michel Cloupeau. Méthode Radio-Electrique pour l'Etude des Ondes de Choc Produites par Décharges Condensées, Roger Der Agobian. Compilation of pa-

pers covering the research in the field of rarefied gases; structure of shock waves; Couette flow in rarefied gases; pressures on cones and flat plates in hypersonic flow; three-dimensional boundary layers; individualization of matter in the flow; occurrence of detonations in gases and formation of waves; shock waves produced in gas tubes by condenser discharges; and methods for studying shock waves generated by condensed discharges.

A STUDY OF SIMILARITY TRANSFORMATIONS FOR THE EQUATIONS OF TWO-DIMENSIONAL INCOMPRESSIBLE VISCOUS FLUID FLOW. Koon-Sang Wan. Polytech. Inst. Bklyn., Dept. Aero. Eng. & Appl. Mech., PIBAL Rep. 537 (AFOSR TN 59-1257), Dec., 1959. 20 pp. Investigation to obtain the possible similarity transformations to a laminar flow equation and the Navier-Stokes equation for two-dimensional unsteady and steady flows in both Cartesian and polar coordinates. As a result, additional similarity transformations are obtained. These include transformations obtained previously in the boundary-layer theory as special cases. The possibilities of applying these transformations to obtain solutions for unsteady and steady laminar boundary-layer problems with external accelerated or decelerated, irrotational or rotational flows, and fixed or moving boundaries, are indicated.

REAL GAS EFFECTS IN FLOW OVER BLUNT BODIES AT HYPERSONIC SPEEDS. H. T. Nagamatsu, R. E. Geiger, and R. E. Sheer, Jr. (IAS Natl. Summer Meeting, Los Angeles, July 8-11, 1958.) J. Aero/Space Sci., Apr., 1960, pp. 241-251. 34 refs. USAF-supported presentation of results from an investigation of representative blunt bodies at hypersonic Mach numbers and nozzle stagnation temperatures up to approximately 6,000°K. These include body pressure distributions, shock wave shapes, detachment distances, and photographs of the luminous gas region in the shock layer. It is seen that the shock detachment distance is smaller at higher stagnation temperatures due to the real gas effects. For the hemisphere, the pressure distribution was less than that predicted by the modified Newtonian theory for all stagnation temperatures. For a 50° cone-hemisphere, the pressure distribution and the shock detachment distance are appreciably affected by the real gas effects.

AN EXPERIMENTAL INVESTIGATION AT A MACH NUMBER OF 4.95 OF FLOW IN THE VICINITY OF A 90° INTERIOR CORNER ALINED WITH THE FREE-STREAM VELOCITY. Appendix - APPROXIMATE METHODS FOR ESTIMATING ERROR CAUSED BY EXCESS MASS IN THE CORNER. P. C. Stainback. US, NASA TN D-184, Feb., 1960. 30 pp. 14 refs. Study considering the effects of the interaction of the shock and the boundary-layer on the static pressure and heat-transfer rate in the vicinity of an interior corner formed by the normal intersection of two planes where the line of intersection is aligned with the free-stream velocity. The results of the investigation indicate that the static pressure in the vicinity of the corner is from 10% to 12% greater than the pressure on a flat plate for the same free-stream conditions. The heat-transfer investigation indicates that the laminar-flow heat-transfer rate in the vicinity of the corner is higher than theoretical values for a flat plate at the same test conditions. The effect of the corner on the heat-transfer rate decreases with both distance from the corner and increasing unit Reynolds number. The effect of the corner on the turbulent-flow heat-transfer rate and the transition Reynolds number is negligible.

ECOULEMENTS NEWTONIENS SUR DES SURFACES CONIQUES EN INCIDENCE. P. Laval. La Recherche Aéronautique, Nov.-Dec., 1959, pp. 5-16. 12 refs. In French. Application of the recently extended Newtonian theory to the case of three-dimensional hypersonic flows of a perfect fluid over conical surfaces of circular and elliptical cross section. The results show the advantages of this theory in determining the aerodynamic characteristics of conical shapes at high Mach Numbers.

THE VISCOUS SECONDARY FLOW AHEAD OF AN INFINITE CYLINDER IN A UNIFORM PARALLEL SHEAR FLOW. Alar Toomre. J. Fluid Mech., Jan., 1960, pp. 145-155. Presentation of a simple method for calculating the secondary velocities and the lateral displacement of total pressure surfaces in the plane of symmetry ahead of an infinitely long cylinder situated normal to a steady, incompressible, slightly viscous shear flow. The cylinder is also perpendicular to the vorticity, which is assumed uniform but small. The method is based on lateral gradients of pressure, these being calculated from the primary flow alone. Profiles of the secondary velocities are obtained at several Reynolds numbers ahead of two specific cylindrical shapes: a circular cylinder, and a flat plate normal to the flow. The displacement effect is derived and is found to be virtually independent of the Reynolds number.

EXPERIMENTS ON THE AXI-SYMMETRIC FLOW OVER AFTERBODIES AND BASES AT M = 2.0. Appendix - THE THEORETICAL PRESSURE DISTRIBUTION ALONG A CONICAL AFTERBODY IN INVISCID FLOW. J. Reid and R. C. Hastings. Gt. Brit., RAE Rep. Aero. 2628, Oct., 1959. 67 pp. Investigation of the effect of profile shape and boundary-layer growth on the distribution of pressure over the side and base of an axisymmetric afterbody in a supersonic stream. Seven models with sealed bases were tested: a cylinder, three truncated cones, and three truncated paraboloids. Supplementary tests were made with the cylinder to investigate the axial pressure distribution behind the base, the influence of a sting on the base pressure, and the interference effect on the base pressure of an isolated disturbance in the free stream. The boundary-layer data are compared with two theoretical methods of calculating boundary-layer growth due to Fraenkel and to Probstein and Elliott; the distribution of afterbody pressure is compared with the theoretical distribution in inviscid flow; and the effect of afterbody angle on the base pressure is

compared with the semiempirical methods of correlation proposed by Chapman and by Cortright and Schroeder.

ON THE FLOW PAST A QUARTER INFINITE PLATE USING OSEEN'S EQUATIONS. K. Stewartson and L. Howarth. J. Fluid Mech., Jan., 1960, pp. 1-21. Analysis of the velocity distribution in the flow past a quarter-plane with its leading edge normal to, and its side edge parallel to, a uniform incident stream. The solution is completed, except for a region in the vicinity of the corner, correct to $\nu^{1/2}$ for small kinematic viscosity ν. The solution is built-up successively from the potential flow associated with the uniform stream and a shear layer to restore the no-slip condition. The normal velocity introduced by this shear layer has to be compensated by a potential flow. This potential flow, in turn, introduces tangential velocities with components parallel to both leading and side edges which require the introduction of a further shear layer. Over the main body of the plate this secondary shear layer is of a conventional form but requires special examination near the edges. It is shown how Carrier and Lewis's solution can be modified to give the flow near the leading edge away from the tip. Finally, the flow near the side edge is determined.

MAGNETOHYDRODYNAMIC FLOW PAST A SPHERE. Kanefusa Gotoh. Phys. Soc. Japan J., Jan., 1960, pp. 189-196. Analysis, using the Oseen approximation, of the flow of an incompressible, viscous, electrically conducting fluid past a sphere in the presence of a uniform magnetic field parallel to the undisturbed flow. The drag coefficient is calculated up to the second order for the Reynolds number, the magnetic Reynolds number, and the Hartmann number. Its numerical values are shown graphically for a few typical cases. It is found that the drag coefficient is continuous at the pressure number S = 1, whereas it changes abruptly at this point in the two-dimensional case.

A LINEARIZED THEORY OF MAGNETOHYDRODYNAMIC FLOW PAST A FIXED BODY IN A PARALLEL MAGNETIC FIELD. Hirowo Yosinobu. Phys. Soc. Japan J., Jan., 1960, pp. 175-188. Application of a perturbation method, similar to the Oseen approximation in ordinary hydrodynamics, to both the flow field and the magnetic field. It shows that the pressure number (the ratio of the magnetic pressure to the dynamic pressure) plays an important role in determining the main features of the field. Detailed calculations are carried out for the flow past a circular cylinder, and an approximate formula for the drag per unit span of the cylinder is obtained.

FLOW OF AN ELECTRICALLY CONDUCTING FLUID PAST A POROUS FLAT PLATE IN THE PRESENCE OF A TRANSVERSE MAGNETIC FIELD. A. S. Gupta. ZAMP, Jan. 25, 1960, pp. 43-50. Analysis of the effect of a transverse magnetic field on the steady flow of an incompressible electrically conducting fluid past an infinite porous flat plate, when the plate is subjected to either suction or injection. Exact solutions have been obtained for the modified Navier-Stokes and Maxwell equations under the usual assumptions of magnetohydrodynamics. The equation of heat transfer, including viscous and Joule dissipation, has also been integrated and the rate of heat transfer calculated.

THE TIME-DEPENDENT MAGNETOHYDRODYNAMIC FLOW PAST A FLAT PLATE G. F. Carrier and H. P. Greenspan. J. Fluid Mech., Jan., 1960, pp. 22-32. Analysis of two magnetohydrodynamic flow problems. The first problem considers a semi-infinite flat plate moving impulsively in its own plane into an electrically conducting viscous fluid in which the ambient magnetic field has the same direction as the motion of the plate. Results are shown to be consistent with the steady flow problem. In the second part, an infinite plate is moved impulsively in its own plane in the presence of an ambient magnetic field which is perpendicular to the plane of the plate. In the analysis, the problem is treated as that of a pipe of very large radius. It is pointed out that the replacement of conceptually acceptable three-dimensional problems by more tractable two-dimensional ones must be carefully justified.

GENERAL THEORY OF ELECTRICALLY CONDUCTING PERFECT GAS FLOW PAST A THREE-DIMENSIONAL THIN BODY. Shigenori Ando. Phys. Soc. Japan J., Jan., 1960, pp. 157-167. Derivation of a fundamental equation of steady flow in terms of a parametric function. The magnetic field, the flow velocity, and the pressure are all connected to the parametric function in such a way that the boundary conditions for the fundamental equation can be written explicitly. The flow over a corrugated wall is treated as an application of the present theory in which the applied magnetic field may be in an arbitrary direction.

STEADY STATE SOLUTIONS OF THE RADIO-FREQUENCY DISCHARGE WITH FLOW. M. F. Romig. Phys. Fluids, Jan.-Feb., 1960, pp. 129-133. Analysis of the electron density distribution and diffusion length for a steady-state, diffusion-controlled radiofrequency discharge acting over a finite portion of an infinite cylinder in which there is a uniform axial gas flow. This model simulates to some extent the flow in a plasma wind tunnel. A qualitative relationship is obtained for the influence of active cylinder length and gas velocity parameter on the diffusion length. The effect of these parameters on the electric field necessary to sustain the discharge is also discussed.

IRREVERSIBLE PROCESSES IN IONIZED GASES. R. Balescu. Phys. Fluids, Jan.-Feb., 1960, pp. 52-63. 27 refs. EOARDC-supported application of the general theory of irreversible processes, developed previously by Prigogine and Balescu, to the case of long range interactions in ionized gases. A similar diagram technique permits the systematic selection of all the contributions to the evolution of the distribution function, to an order of approxi-

mately equivalent to Debye's equilibrium theory. The infinite series which appear in this way can be summed exactly. The resulting evolution equations describe interactions of "quasi-particles," which are electrons or ions "dressed" by their polarization clouds. These clouds are not a permanent feature, as in equilibrium theory, but have a nonequilibrium, changing shape, distorted by the motion of the particles.

MAGNETOHYDRODYNAMIC EFFECTS ON EXOTHERMAL WAVES. R. A. Gross, W. Chinitz, and T. J. Rivlin. J. Aero/Space Sci., Apr., 1960, pp. 283-290. 15 refs. USAF-sponsored analysis of the elementary magnetohydrodynamic effects on exothermal, plane supersonic waves. One-dimensional steady flow with heat addition in the presence of a plane magnetic field transverse to the direction of motion is studied. Basic equations are derived and solved numerically for several ideal conditions which correspond to gaseous detonations and thermonuclear shocks. The magnetic field acts on the flow in a way which tends to counteract the heat-addition effects. The singular solution still exhibits the classical Chapman-Jouguet conditions. Some properties of high-temperature gas mixtures are presented, including the electrical conductivity of air shocks and fuel-air detonations. Experimental implications of the analysis and numerical results are discussed.

CONTRIBUTION A LA THEORIE DES ONDES DE CHOC EN MAGNETODYNAMIQUE DES FLUIDES. P. Germain. France, ONERA Pub. 97, 1959. 33 pp. 17 refs. In French. Investigation covering the theory of shock waves in magnetohydrodynamics. The derivation of general equations is explained in detail, and a definition of the differential system is given along with the formulation of the problem. The case of shocks in perfect fluids is studied, neglecting the dissipation mechanisms; solutions are obtained for the linear system representing the asymptotic behavior of the nonlinear system in the neighborhood of a singular point; and the results are presented on the existence and uniqueness of a rapid shock, the instability - i.e., the nonexistence of intermediate shocks, and the possibility of a stable slow shock.

O MAGNITOGIDRODINAMICHESKIKH UDARNYKH VOLNAKH, IONIZUIUSHCHIKH GAZ. A. G. Kulikovskii and G. A. Liubimov. AN SSSR Dokl., Nov. 1, 1959, pp. 52-55. In Russian. Study of the structure of magnetohydrodynamic waves ionizing the gas. Considered are cases where only two dissipative coefficients - i.e., magnetic viscosity and molecular viscosity, or magnetic viscosity and thermal conductivity - are different from zero. It is assumed that the magnetic and electric fields are normal to each other and parallel to the plane of the wave front. The piston problem is also covered.

OPTIMUM POWER GENERATION FROM A MOVING PLASMA. J. L. Neuringer. J. Fluid Mech., Feb., 1960, pp. 287-301. USAF-supported analysis considering the following two problems: (1) the extraction of optimum power from the steady one-dimensional flow of an incompressible inviscid plasma across a uniform transverse magnetic field in an externally loaded channel of arbitrarily varying cross section, and (2) the extraction of optimum power from the steady one-dimensional flow of a compressible inviscid plasma across a uniform transverse magnetic field in a channel of uniform cross section. In each case, the magnitude of the required external loading at optimum power operation is determined as a function of the parameters which characterize the hydromagnetic interaction. Also determined are the magnitudes of the terminal voltage, power, fluid mechanical to electrical conversion efficiency, and the variation of the fluid dynamic variables along the channel at optimum power.

FLOW ABOUT AN UNSTEADILY ROTATING DISC. E. M. Sparrow and J. L. Gregg. J. Aero/Space Sci., Apr., 1960, pp. 252-256, 290. Analysis of the unsteady laminar flow about a rotating disc whose angular velocity ω may vary with time. The deviation of the actual instantaneous state of the flow from the quasi-steady state (instantaneous steady state) is determined. From this, a simplified criterion is derived to define the conditions under which the flow can be considered as quasi-steady for the purposes of shear stress and torque computations. Since a turbulent flow responds more rapidly than a laminar flow, the quasi-steady criterion should also serve for the turbulent case.

A GRAPHICAL SOLUTION OF SHOCK EQUATIONS. Ch. E. Treanor and M. J. Williams. Cornell Aero. Lab. Rep. AD-1118-A-4 (AFOSR TN 59-1088), Nov., 1959. 32 pp. Presentation of a rapid graphical method for calculating the conditions behind a normal shock. The method applies to any gas for which the enthalpy is known as a function of pressure and density. The accuracy is limited only by that of the available graph of the gas properties. The necessary working graphs for air, O_2 and N_2 (complete thermodynamic equilibrium), and for NO (without chemical reaction) are included, along with a template for use in attaining the solution.

ON THE STABILITY OF ONE-DIMENSIONAL VISCOUS FLOWS: SOUND WAVES AND SHOCK WAVES. L. G. Kaufman, II, and Morris Morduchow. USAF WADC TR 59-355, Aug., 1959. 44 pp. 29 refs. Development of a set of two linear homogeneous, simultaneous, ordinary differential equations for small one-dimensional disturbances, based on the one-dimensional Navier-Stokes equations with viscosity and heat conduction and with Prandtl number equal to 3/4. The steady flow solutions analyzed are uniform flows and normal shock waves. The solutions for the disturbances in uniform flows can be interpreted as damped sound waves, and indicate that the uniform flows in a viscous fluid are stable. The solutions for the disturbances in normal shock waves are obtained by approximate methods and indicate that

for all (supersonic) Mach numbers for which the Navier-Stokes equations are valid, disturbances having wavelengths greater than about a ten thousandth of an inch will tend to amplify with time. Thus, the steady shock-wave solutions of the one-dimensional Navier-Stokes equations are unstable.

THE PROPAGATION OF SHOCK WAVES OF CONSTANT STRENGTH. A. G. Mackie and D. G. Weir. Cambridge Philos. Soc. Proc., Jan., 1960, pp. 64-74. Study of conditions under which plane shock waves of constant strength can propagate through a gas in a given homentropic motion. Since the entropy change across the shock is taken to be constant, homentropic flow exists also behind the shock. The motion behind the shock is determined by solving a Cauchy problem with data given on the back of the shock. The theory is illustrated by two examples, one of which generalizes a result obtained by Copson.

A METHOD OF SOLUTION WITH TABULATED RESULTS FOR THE ATTACHED OBLIQUE SHOCK-WAVE SYSTEM FOR SURFACES AT VARIOUS ANGLES OF ATTACK, SWEEP, AND DIHEDRAL IN AN EQUILIBRIUM REAL GAS INCLUDING THE ATMOSPHERE. Appendix A - ALTERNATE METHOD FOR SOLUTION TO SWEPT LEADING EDGES. Appendix B - EQUILIBRIUM RELATIONS FOR OBLIQUE SHOCKS IN A REAL GAS. R. L. Trimpi and R. A. Jones. US, NASA TR R-63, 1960. 157 pp. 10 refs. Presentation of a new method for solving the attached oblique shock-wave system for surfaces at various angles of attack, sweep, and dihedral in any real gas in equilibrium. Results are tabulated for the following ranges: angle of attack, 0° to 65°; angle of sweep, 0° to 75°; angle of dihedral, 0° to 30°; Mach number, 3 to 30; and "effective specific-heat ratio" parameter, 1.10 to 1.67. Both the method and tabulated solutions are easily adaptable to flight in any gas or in the atmosphere of any planet.

SHOCK-WAVE STRUCTURE BASED ON IKENBERRY-TRUESDELL APPROACH TO KINETIC THEORY OF GASES. R. E. Street. US, NASA TN D-365, Feb., 1960. 60 pp. 12 refs. Presentation of a brief review of the Ikenberry-Truesdell method of solution of the Boltzmann equation, in which emphasis is placed upon the procedure called Maxwellian iteration. Corrections to the various iterations are made. This approach is then applied to the problem of shock-wave structure. A series solution of the type used by Grad for his equation and by Talbot and Sherman for the Chapman-Enskog equations is used to find the velocity and temperature profiles for a steady, plane shock wave in an ideal gas of Maxwellian molecules.

A THREE-DIMENSIONAL LINEARIZED ANALYSIS OF THE FORCES EXERTED ON A RIGID WING BY A SHOCK WAVE. F. E. Ehlers and E. M. Shoemaker. J. Aero/Space Sci., Apr., 1960, pp. 257-260. Extension of a previous analysis to the case where the shock wave is not parallel to the edge of the half-plane. The three-dimensional problem is reduced to the two-dimensional case and solved for the pressure distribution over the wing.

A REFINEMENT OF THE LINEARIZED TRANSONIC FLOW THEORY. Iwao Hosokawa. Phys. Soc. Japan J., Jan., 1960, pp. 149-157. 12 refs. Presentation of a new method to calculate the velocity and pressure distributions around a thin symmetrical airfoil or a slender body of revolution flying at transonic speed. It is essentially a refinement of the linearized transonic flow theory due to Oswatitsch and Maeder, such that a correction term is introduced to take account of the nonlinear character of the transonic flow. As examples of the application, a symmetrical circular-arc airfoil and a circular-arc body of revolution in the sonic flow are dealt with, and the results are found to be in good agreement with experiments, except for the rear portion in the latter case.

ONE-DIMENSIONAL EQUILIBRIUM SPECTRA IN ISOTROPIC TURBULENCE. W. H. Reid. Phys. Fluids, Jan.-Feb., 1960, pp. 72-77. 12 refs. ONR-supported presentation of the one-dimensional equilibrium spectra in isotropic turbulence for the physical transfer theories of Heisenberg, Kovásznay, and Obukhoff, including a comparison with experimental measurements. For two of the theories (Heisenberg's and Kovásznay's), reasonable agreement is obtained for the wave number $k\eta < 0.04$, but for larger values of $k\eta$ there is considerable divergence between theoretical and experimental results. The relationship between the equilibrium and similarity spectra is also discussed for these two theories.

Internal Flow

NIEKTÓRE WYNIKI BADAŃ DOŚWIADCZALNYCH PALISADY KIEROWNICZYCH ŁOPATEK TURBINOWYCH O MAŁEJ WYSOKOŚCI. Józef Śmigielski and Romuald Puzyrewski. Arch. Budowy Maszyn, No. 3, 1959, pp. 363-380. In Polish, with summaries in English and Russian. Investigation of a cascade of turbine nozzle blades of small height ($0.38 \leq 1/b \leq 0.97$) with velocities corresponding to the Mach number of $0.25 \leq M_2 \leq 0.58$. The results include the measurement of the outlet angle and the magnitude of losses, taking into consideration, besides the changes of the ratio l/b and the Mach number, the changes of the pitch t/b and the ratio of the width of the outlet to the height of the blades. Certain conclusions are drawn from the results concerning the effects of the individual parameters.

WPŁYW TARCIA NA ROZPRĘŻANIE GAZU W SKOŚNYM ŚCIĘCIU KIEROWNIC TURBINOWYCH. Leon Niemand. Arch. Budowy Maszyn, No. 3, 1959, pp. 407-426. In Polish, with summaries in English and Russian. Discussion of the effect of friction upon gas expansion in the oblique section of turbine guide vanes. By means of the integration of the equation of flow between the critical and the minimum sections, an expression is obtained for the Laval number for the minimal guide section as a function of the friction coefficient c_f and the overall dimensions of the transit duct of the vanes. Considering the entropy increment between the critical and the minimal sections, an expression is obtained for the velocity coeffi-

cient φ for the subcritical part of the guides as a function of the friction coefficient c_f and its geometric parameters. It is shown that in order to obtain an exit gas velocity equal to the critical, it is necessary to have a pressure ratio smaller than $[2/(\varkappa + 1)]^{\varkappa/(\varkappa - 1)}$, where $\varkappa$ is the isentropic exponent. The value of this ratio depends mainly upon the friction coefficient c_f, the Laval number, and the guide vane angle of inclination. The velocity coefficient for the cascade, comprising the oblique section, depends on the Laval number and is a function of the enthalpy drop.

PORÓWNANIE POD WZGLĘDEM SPRAWNOŚCI REGULACJI STAŁEGO CIŚNIENIA SPRĘŻAREK ODŚRODKOWYCH DZIAŁAJĄCYCH NA ZASADZIE DŁAWIENIA W RUROCIĄGU TŁOCZNYM, DŁAWIENIA W RUROCIĄGU SSAWNYM LUB NASTAWNYCH ŁOPATEK DYFUZORÓW. Andrzej Wszelaczyński. Arch. Budowy Maszyn, No. 3, 1959, pp. 381-405. In Polish, with summaries in English and Russian. Comparison of the constant pressure regulation efficiency of centrifugal compressors considering the principle of choking in the section duct, choking in the forcing duct, or the use of adjustable diffusor vanes. "Regulation efficiency" is defined in mathematical terms by means of an equation which holds for all three methods of regulation considered. It is found that the efficiency of regulation by adjustable diffusor vanes is greater than that by choking in the forcing duct. Regulation by choking in the section duct is the least efficient.

AN INVESTIGATION OF DIFFUSION IN A SUPERSONIC COMPRESSOR STATOR BY MEANS OF AERODYNAMIC CONTROL. V. D. Agosta and J. P. DeCarlo. Polytech. Inst. Bklyn., Dept. Aero. Eng. & Appl. Mech., PIBAL Rep. 531, Dec., 1959. 46 pp. 20 refs. ONR-sponsored application of a two-dimensional approach to the design of a Mach 3 supersonic diffuser which included the use of bleed ports to satisfy starting requirements. The experimental approach was conducted so that the maximum pressure recovery was achieved for a minimum of air bleed. In addition, a geometrical scaling technique to increase the mass flow through the diffuser without losses in pressure recovery was devised. The particular advantages of employing a compressor operating supersonically enable the design of a smaller, lower weight turbojet engine operating at a thrust comparable to that of a conventional jet engine. For an increase in the entrance Mach number from 2.00 to 2.57, a 37% increase in thrust and a 6.1% decrease in specific fuel consumption are achieved.

EFFECT OF A VARIABLE-GEOMETRY DIFFUSER ON THE OPERATING CHARACTERISTICS OF A HELIUM TUNNEL DESIGNED FOR A MACH NUMBER IN EXCESS OF 20. P. J. Johnston and R. D. Witcofski. US, NASA TN D-237, Feb., 1960. 20 pp. Experimental investigation conducted in a 3-in. helium tunnel equipped with a conical nozzle and operating at a Mach number of 20 to determine the effectiveness of variable-geometry supersonic diffusers in decreasing the overall pressure ratio required to maintain flow. Four diffuser entrance wall lengths are investigated. The results indicate that the overall pressure ratio required to maintain flow, if a constant-area diffuser is used, could be decreased 34% by utilizing an optimum combination of diffuser entrance wall length and diffuser entrance wall angle. For this combination, only 61% of test-section pitot pressure could be recovered by the diffuser.

FORCE-MOMENTUM FIELDS IN A DUAL-JET FLOW. D. R. Miller and E. W. Comings. J. Fluid Mech., Feb., 1960, pp. 237-256. Presentation of measurements for the mean velocity, mean flow direction, normal turbulent stress in the direction of flow, and mean static pressure of the subsonic flow field generated by identical twin jets of air issuing from parallel slot nozzles. At the low nozzle velocity employed (72ft./sec.), the flow was effectively incompressible. Since the end walls prevented interjet air entrainment from the surroundings, a region of highly convergent flow was formed near the nozzles. In this region, contour maps clearly reveal (1) the sub-atmospheric static pressure trough that accounts for the jet convergence, (2) a free stagnation point on the plane of symmetry, (3) stable symmetrical contrarotary vortices which recycle air on the concave side of each converging jet, and (4) the superatmospheric static pressure mound that redirects the merging jet streams in a common downstream direction.

THE STABILITY AND TRANSITION OF A TWO-DIMENSIONAL JET. Hiroshi Sato. J. Fluid Mech., Jan., 1960, pp. 53-80. 17 refs. Experimental and theoretical investigation of the transition in a jet. In the region where laminar flow becomes unstable, two kinds of sinusoidal velocity fluctuations have been found; one is symmetrical and the other is antisymmetrical with respect to the centerline of the jet. The fluctuations grow exponentially at first, and develop into turbulence without being accompanied by abrupt bursts or turbulent spots. The response characteristics of laminar jets to artificial external excitation are investigated in detail by using sound as an exciting agent. The effect of excitation was seen most clearly when the frequency of excitation coincided with that of self-excited sinusoidal fluctuations. Numerical solutions of the equation of small disturbances superposed on laminar flow were obtained assuming the Reynolds number as infinity. Theoretical eigenvalues and eigenfunctions are in good agreement with experimental results, thus verifying the existence of a region of linear disturbance in the two-dimensional jet.

EXPERIMENTAL INVESTIGATION OF MIXING OF MACH NUMBER 3.95 STREAM IN PRESENCE OF WALL. Marian Visich, Jr., and P. A. Libby. US, NASA TN D-247, Feb., 1960. 47 pp. 18 refs. Study of the turbulent mixing of a supersonic stream with a subsonic stream bounded by a wall. The mainstream is kept at a constant Mach number while the mass flow of the secondary stream is varied from zero to a value assuring subsonic flow at the origin of mixing. The difficulties as-

sociated with a theoretical treatment of the flow are discussed; the test rig and the testing techniques are described; and the static pressure distributions along the lower wall and the total head distributions at three downstream stations, for various Mach numbers in the secondary flow, are studied. The total-head profiles are interpreted in terms of velocity profiles which are then correlated in terms of an extension of the law of the wall and the law of the wake to compressible flow.

Wings & Airfoils

COMPUTATION OF THE INCREMENT OF MAXIMUM LIFT DUE TO FLAPS. A. Roshko. Douglas Rep. SM-23626, July 13, 1959. 9 pp. Development of a method for correlating stall, other than that due to Rettie, using thin airfoil theory, and verification of the concept that $C_{l_{max}}$ can be correlated for thin airfoils having the same nose. The values of the ideal angle of attack (α_i) and the basic lift at this angle (C_{l_b}) are computed for an uncambered symmetrical airfoil with leading edge or trailing edge flaps. A method is shown for extending this correlation to the cambered airfoil. Comparison is made with experiments for the leading edge flap and shows good correlation up to a flap angle of 20°.

THE EFFECT ON THE DRAG OF A WING-BODY COMBINATION OF MOMENT-OF-AREA-RULE MODIFICATIONS WITH PODS DUCTED TO SIMULATE ENGINE NACELLES. R. R. Dickey and L. L. Levy, Jr. US, NASA TN D-308, Feb., 1960. 15 pp. 11 refs. Experimental investigation to determine if moment-of-area-rule modifications with pods ducted to simulate engine nacelles are as effective for reducing the wave drag of wing-body combinations as moment-of-area-rule modifications with unducted pods. The zero-lift drag of a basic wing-body combination with an elliptic plan form wing of aspect ratio 3.0 and of the basic model with two separate moment-of-area-rule modifications is measured at Mach numbers from 0.6 to 1.4. The two modified models are identical except that the inboard pods of one of the models are ducted to simulate engine nacelles with internal-compression-type inlets. The results indicate that the modifications utilizing inboard pods ducted to simulate engine nacelles are at least as effective as the modifications utilizing unducted pods for reducing the wave drag, and that modifications with either ducted or unducted pods provide large reductions in wave drag.

AEROELASTICITY

BEAM VIBRATIONS WITH QUASI-ORTHOGONAL BOUNDARY CONDITIONS. Y. C. Das, L. E. Goodman, and A. R. Robinson. USAF WADC TR 59-76, Nov., 1959. 39 pp. Development of an exact solution for the transient and steady-state motion of beams when rotational or translational viscous damping enters the boundary conditions. The method is applicable to any structures whose governing differential equations and boundary conditions would, in the absence of energy dissipation, constitute a classical Sturm-Liouville system. The unusual feature of the method is that the displacement and velocity are considered as two independent functions and the kinematic relation between them is not immediately imposed. Quasi-orthogonality relations which are obtained for any set of two modes permit expansion of any sufficiently smooth function in a series of eigenfunctions. This makes the completion of the solution possible.

PRESSURE DISTRIBUTION AND FLUTTER ANALYSIS OF LOW-ASPECT-RATIO WINGS IN SUBSONIC FLOW. Pao-Tan Hsu and W. H. Weatherill. MIT ASRL TR 64-3, June, 1959. 47 pp. 21 refs. Navy-supported application of a numerical solution of the subsonic compressible flow pressure-downwash integral equation to obtain results for pressure distributions over oscillating rectangular and delta wings, presented together with a flutter analysis of a delta wing and a method for handling the effects of an aileron on a two-dimensional oscillating airfoil. The work is based on the methods presented previously by Hsu, in which an assumed series is used to represent the pressure for which the coefficients are evaluated using the known downwash. Numerical evaluation of the integral is carried out using sets of integration and collocation stations preselected in such a fashion as to yield optimum results. Lift and moment coefficients and their corresponding phase angles are calculated for rectangular wings of aspect ratio 1.0 and 2.0 and delta wings of aspect ratio 1.07 and 2.31 undergoing vertical translation and pitch about the mid-chord motions. To extend the kernel function method to include the effect of a control surface, a logarithmically singular pressure distribution term is included in the pressure series.

WIND TUNNEL TESTS ON THE FLUTTER OF A SWEPT AND UNSWEPT WING WITH AILERONS. H. Hall and J. A. Rein. Gt. Brit., RAE Rep. Struc. 253, Oct., 1959. 13 pp. Presentation of the results of low-speed flutter tests on an unswept and a 40° sweptback wing, each wing having a half span, quarter chord aileron. The aileron mass balance and hinge stiffness were varied in the tests. The limiting value of the mass balance, above which flutter of the wing flexure-aileron rotation type does not occur, is determined. Flutter calculations are made which give very good agreement with the measured characteristics of the unswept wing and reasonable agreement with the swept wing.

CONTROLE PAR MAQUETTES PROPULSEES SOL-SOL DE COEFFICIENTS AERODYNAMIQUES DE FLOTTEMENTS DETERMINES EN SOUFFLERIE. R. Destuynder. La Recherche Aéronautique, Nov.-Dec., 1959, pp. 41-45. In French. Description of experiments used to obtain data for the design of full-scale structures. The procedure comprises wind-tunnel tests on models for determining the nonstationary aerodynamic coefficients; the results are then verified on transonic or supersonic free-flight models. Results obtained on

eight different models are given and the experimental methods are described in detail.

A PROBABILITY ANALYSIS OF COINCIDENT GUST AND MANOEUVRE LOADS IN LOW-FLYING AIRCRAFT. S. D. Baxter, J. Liiva, and R. T. Sewell. Canada, NRC Aero. Rep. LR-264, Nov. 17, 1959. 30 pp. Analysis considering the frequency distribution of the joint occurrence of a gust and a maneuver and, from this, calculation of the hours to equal or exceed preassigned load levels. Results are obtained by two methods of solution - one, a purely mathematical approach, and the other, electrical simulation.

LOW FREQUENCY FLEXURAL VIBRATIONS IN ELASTIC PLATES. V. T. Buchwald. Quart. J. Mech. & Appl. Math., Nov., 1959, pp. 454-463. Analysis showing that simple assumptions about the transverse displacement and the shear stresses lead to two equations for flexural vibrations of plates, corresponding to three modes of vibration. The equations obtained are compared with the exact solutions for the propagation of plane flexural waves, and it is shown that if the frequency is less than a certain value, correspondence is very good between the two sets of equations. The results are also compared with similar results obtained from Mindlin's equations.

AIRPLANES

Air Conditioning, Pressurization

DECOMPRESSION OF A PUNCTURED PRESSURIZED CABIN. S. T. Demetriades. Northrop ND Rep. NB-59-224, Sept. 1, 1959. 34 pp. 10 refs. Development of expressions for the flow velocity, density, and pressure, at any point in a cabin which is suddenly punctured, until the instant the reflected rarefaction wave reaches the point. These expressions apply to holes of any size and for ambient pressures of any magnitude. Methods are presented (a) for calculating the forces on bodies in the cabin and on the body of the vehicle due to the flow of gas out of the cabin and (b) for estimating the time necessary for decompression to any lower pressure. These forces may be large compared to all other dynamic and propulsion loads. It is concluded that for holes of size equal in order of magnitude to the cross-sectional area of the cabin, the results of a sudden decompression are rapid and catastrophic. Small holes present less danger.

Control Systems, Automatic Pilots

ON THE DESIGN OF A HIGH-GAIN SATURATING CONTROL SYSTEM FOR USE AS AN ADAPTIVE AUTOPILOT. Appendix - DERIVATION OF LIMITER GAIN IN THE PRESENCE OF DITHER. J. D. McLean and S. F. Schmidt. US, NASA TN D-305, Feb., 1960. 48 pp. Analysis showing that the system studied can control an aircraft over very large ranges of flight conditions without resort to air data measurements. Analytical methods are presented for predicting the frequency, amplitude, and effect on performance of the inherent limit cycle or "chatter." Methods are also given for reducing the chatter amplitude and its undesirable effects on the low-frequency response. At low dynamic pressures, limiting and low aerodynamic gain can result in poor damping or instability. One method of compensating for this difficulty is presented.

DOCUMENTATION

THE CONSTRUCTION OF RESEARCH FILMS. D. H. Densham. NATO AGARDograph 33, 1959. Published for and on behalf of AGARD, NATO, by Pergamon Press, 1959. 104 pp. $4.50; 30 s. Presentation of information designed to give sponsors and scientists an approach to documentary and educational film making. Basic principles are covered, including the adoption of a small budget to give maximum use with limited means and equipment and the full employment of existing research material. Discussion includes the equipment technicians should use, latest developments in color filming, magnetic tape recording, and modern motion picture equipment. Problems of lighting, sound, animation, and editing are covered, and common faults are shown.

MISSILE, ROCKET, & SPACE TECHNOLOGY

THE FIRST SIX SKYLARK FIRINGS. E. B. Dorling. Gt. Brit., RAE TN G.W. 530, Oct., 1959. 116 pp. 14 refs. Discussion of the Skylark high altitude rocket, designed to carry payloads of 100-150 lb. to heights up to 100 miles using a Raven solid propellant motor. The design, instrumentation, aerodynamics, and performance of the rocket are described. Details of the six firings are given, including the results of some high-altitude experiments.

STEP-ROCKETS. Josef Schmidtmayer. Acta Technica, No. 5, 1959, pp. 379-403. 23 refs. Analysis of multi-stage rockets by means of a triad of dimensionless parameters first used by Vertregt. The relations between these parameters and the masses of the subrockets and their parts are given, and some general conclusions are deduced for the optimum design of a step-rocket. Some results are given which make possible a rapid estimate of the total mass of a step-rocket, if the exhaust velocities and, similarly, the structural parameters of all steps are equal to each other.

Ballistics, Re-Entry

REQUIREMENTS OF TRAJECTORY CORRECTIVE IMPULSES DURING THE APPROACH PHASE OF AN INTERPLANETARY MISSION. Appendix A - OPTIMUM SOLUTION - SPECIAL CASE ($R = R_{p_1}$). Appendix B - VELOCITY IMPULSES ALINED IN DIRECTIONS OTHER THAN OPTIMUM. Appendix C - DEVELOPMENT OF EQUATIONS DESCRIBING TRANSFER MANEUVERS. A. L. Friedlander and D. P. Harry, III. US, NASA TN D-255, Jan., 1960. 53 pp. Analysis of the minimum velocity impulse required to correct off-course trajectories. The target is defined

in terms of the perigree distance. The equations derived are limited to two-dimensional motion in a symmetrical inverse-square central force field. The magnitude of the minimum velocity vector is presented in dimensionless form for an extensive range of initial conditions. The contribution of corrective impulses to the total requirements of a round-trip Mars mission is shown. Expressions for the errors in corrected perigree (miss distance) due to magnitude and alignment errors of the applied thrust are derived.

NECESSARY CONDITIONS FOR OPTIMAL ROCKET TRAJECTORIES. D. F. Lawden. Quart. J. Mech. & Appl. Math., Nov., 1959, pp. 476-487. Analysis which expresses the problem of transferring a rocket with minimum expenditure of propellant between two terminals in a given gravitational field and in the absence of aerodynamic forces as a Mayer type problem in the calculus of variations. The known solution to this problem is employed to yield a set of necessary conditions to be satisfied by the optimal trajectory. As an illustration of the general results, the particular case, when the yield is uniform, is solved.

THEOREM OF IMAGE TRAJECTORIES IN THE EARTH-MOON SPACE. Angelo Miele. Boeing Sci. Res. Lab. FSL Rep. 21, D1-82-0039, Jan., 1960. 14 pp. Analysis considering the motion of a small vehicle in the earth-moon space under several hypotheses relative to the behavior of the earth-moon system. Two theorems associated with the relative motion of the vehicle are established: the theorem of image trajectories and the irreversibility theorem. The theorem of image trajectories states that, if a trajectory is physically possible in the earth-moon space, the image of this trajectory with respect to the earth-moon axis is also physically possible, provided the image trajectory is in the opposite sense. This reduces the time necessary for analyses since a set of moon-to-earth trajectories can be obtained by a simple transformation of coordinates, once the corresponding set of earth-to-moon trajectories is calculated. The irreversibility theorem states that, if a trajectory is physically possible in the earth-moon space, the reverse trajectory is not physically possible. Finally, the case of a looped trajectory is considered and, as a corollary to these two theorems, it is shown that all looped paths of artificial satellites of the earth-moon system are asymmetric with respect to the earth-moon axis.

ZUR AUSWAHL VON FLUGBAHNEN FÜR BEMANNTE RAUMFAHRZEUGE ZU DEN PLANETEN MARS UND VENUS. K. A. Ehricke. Raketentech. & Raumfahrtforsch., Jan.-Mar., 1960, pp. 16-22. 10 refs. In German. Investigation of the parameters for the selection of transfer orbits to Mars and Venus for the case of manned space missions, in particular, a short mission period. The minimum-time transfer orbits require a higher performance of the propulsion system, but, compared to the Hohmann transfer orbits, are less limited in the selection of departure time and allow a variation of the waiting period.

Guidance, Control, Stability

STATIC STABILITY AND SEPARATION CHARACTERISTICS OF A TWO-STAGE ROCKET CONFIGURATION AT MACH NUMBERS FROM 1.57 TO 4.50. K. L. Turner, D. S. Shaw, and L. W. Enderson, Jr. US, NASA TN D-188, Jan., 1960. 35 pp. Investigation conducted on a model of a two-stage rocket at Reynolds numbers per ft. from 1.5×10^6 to 4.0×10^6. The stages are tested separately, combined, and during systematic separation from each other. Results indicate that the complete model is statically stable throughout the test Mach number range. The stability and normal-force parameters decrease with an increase in Mach number. The complete configuration should incorporate larger fins to insure a positive static margin throughout the test Mach number range. At a model roll angle of 90° the complete configuration is more stable and produces more normal force than a model at roll angle of 0°. Stage II is stable and produces positive normal force at a Mach number of 4.50. To insure a successful separation of the two stages, it appears that stage II should be ignited before separation.

ON MID-COURSE GUIDANCE IN SATELLITE INTERCEPTION. G. W. Morgenthaler. Astronautica Acta, Fasc. 6, 1959, pp. 328--346. USAF-supported analysis which assumes that the intercepting rocket vehicle has attained an orbit and small mid-course velocity corrections are desired to place the rocket in proximity to the satellite so that terminal guidance schemes may effect the rendezvous. This constitutes a central force, mid-course, guidance problem of the first-order correction type involving small, impulsive corrective thrusts. Precision mid-course guidance may be attained by repetition of the scheme at several points en route. The guidance equations are developed, and a method of solution is described on the basis of the impulsive correction assumption.

Spacecraft

MOTION OF A SATELLITE IN THE EARTH'S GRAVITATIONAL FIELD. G. V. Groves. Royal Soc. (London) Proc., Ser. A, Jan. 19, 1960, pp. 48-65. Development of equations of motion considering the precession and nutation of the earth. The main part of the study deals with the motion arising from the gravitational field of the earth, expressed as a general expansion in spherical harmonics. By evaluating the partial derivatives in Lagrange's planetary equations, expressions are obtained for the rates of change of the orbital elements. Particular consideration is given to the form of the expressions for the secular terms arising from the first four zonal harmonics.

A UNIFIED ANALYTICAL DESCRIPTION OF SATELLITE ATTITUDE MOTIONS. R. E. Roberson. (ARS 13th Annual Meeting, New York, Nov. 17-21, 1958.) Astronautica Acta, Fasc. 6, 1959, pp. 347-355. Study in which previous formulations of the equations of satellite attitude motion and the perturbation torques on the satellite are unified and generalized. Equations of motion are develop-

ed in terms of arbitrarily large attitude deviation angles relative to an arbitrary attitude reference frame. Explicit expressions are obtained for effective external and parametric excitation torques from internal moving parts, inertial reaction control parts, and motion of the attitude reference frame. The gravitational torque on the satellite is given in the sense of a definite sequence of manipulations, although the final result is not explicit. The equations of motion are linearized, and an expression is derived for the excitation torque which arises from the second-order terms usually neglected.

ON SATELLITE ORBITS. IV - SOME NEW METHODS OF SATELLITE ORBIT CALCULATIONS AND STABILITY PROBLEMS. Herbert Knothe. USAF MDC TR 59-37, Sept., 1959. 21 pp. Presentation of three refinements to previous calculations on orbit mechanics. The equations of motion of a satellite are reduced to a system of two ordinary first-order differential equations, considering rotationally symmetric gravitational anomalies. A system of three ordinary first-order differential equations is derived to describe the osculating ellipse. Finally, a differential geometrical approach is applied which leads to simple formulas for the calculation of the regression. A vector integral equation is derived for the deviation of the satellite from the plane of the initial osculating ellipse.

THE CONTRACTION OF SATELLITE ORBITS UNDER THE INFLUENCE OF AIR DRAG. I - WITH SPHERICALLY SYMMETRICAL ATMOSPHERE. D. G. King-Hele, G. E. Cook, and D. M. C. Walker. Gt. Brit., RAE TN G.W. 533, Nov., 1959. 46 pp. 21 refs. Analysis, by a perturbation method, of the effect of air drag on satellite orbits of small eccentricity $e(< 0.2)$, on the assumption that the atmosphere is spherically symmetrical. Equations are derived which show (1) how orbital period and perigee distance vary with eccentricity as the orbit contracts, and (2) how each of these quantities varies with time. The equations of type (1) are nearly independent of the oblateness of the atmosphere. In all the equations, terms of order e^4 and higher are usually neglected.

AERODYNAMIC DRAG OF NEAR EARTH SATELLITES. Appendix - THE DRAG OF AN INCLINED CIRCULAR CYLINDER. G. E. Cook. Gt. Brit., RAE TN G.W. 531, Sept., 1959. 45 pp. 15 refs. Discussion of the drag of a body in free molecule flow and the flow regime appropriate to a satellite in orbit. The molecular speed ratio is related to the properties of the upper atmosphere. The mechanism of molecular reflection at the satellite's surface and the surface temperature are considered. The drag coefficients of some simple shapes are quoted for appropriate molecular speed ratios, and the drag coefficients are obtained for cylinders and a cone with axes inclined at any angle to the direction of motion.

NUCLEAR ENERGY

RAPID APPROXIMATE METHOD FOR ANALYZING NUCLEAR ROCKET PERFORMANCE. A. H. Stenning. ARS J., Feb., 1960, pp. 169-172. Study of the effects of core geometry and surface temperature limitations on nuclear rocket performance, using the heat-transfer friction analogy and one-dimensional gasdynamics. Approximate relationships between thrust coefficient, specific impulse, core geometry, and maximum surface temperature are obtained. High thrust coefficient and high specific impulse are not compatible, and a compromise must be made between these two requirements.

POWER PLANTS

NEW PROPULSION CONCEPTS. S. T. Demetriades. Northrop ND Rep. NB-59-176, July 1, 1959. 43 pp. Presentation of a logical scheme for generating a large number of propulsion systems. The implications of two of these systems are examined. It is shown how a propulsive fluid accumulator (PROFAC), using a magnetogasdynamic (MGD) orbital ramjet to collect expellant in low-altitude orbit in the upper atmosphere around a planet, could bring about a decrease of the payload ratios required in space missions by one or more orders of magnitude or an increase of the payload, for a given initial take-off mass, by one or more orders of magnitude, without any required increase in specific impulse. It is further suggested that great improvements in the economics of space flight could result from the use of "pusher beams" - i.e., beams of energy or particles directed at a spaceship to push it onward.

EXPERIMENT TO OBTAIN REACTION THRUST IN A LABORATORY MODEL OF AN ION ENGINE. Yu. Ya. Stavisskii, I. I. Bondarenko, V. I. Krotov, S. Ya. Lebedev, V. Ya. Pupko, and E. A. Stumbur. Sov. Phys. - Tech. Phys., Feb., 1960, pp. 875-878. Translation. Discussion of the principles of an ion engine and some of the problems in its construction. Such problems include neutralizing the space charge in the ion beam, the elimination of parasitic electron current from the space charge compensation system to the ion emitter, and the reduction of erosion (cathode disintegration) by the accelerated ions. Experimental investigations are carried out on a simplified model of the ion engine in which surface ionization of cesium on tungsten is used. The thrust is measured by a balance system having a nickel plate located in the path of the beam. In the model described, there is considerable loss of neutral cesium atoms because part of the atomic beam which issues from the aperture goes past the emission surface. These losses can be reduced through the use of alternate systems for supplying cesium to the emission surface.

Ram-Jet & Pulse-Jet

BETRACHTUNGEN ZUR AUSLEGUNG VON STAUSTRAHLTRIEBWERKEN. Hermann Hagen. ZFW, Jan., 1960, pp. 17-22. 12 refs. In German. Presentation of diagrams on the conditions which are important for the intake and the flow in the combustion chamber of a ram-jet, based on the knowledge of the losses occurring in a ram-jet.

From these diagrams, conclusions can be drawn concerning the dependence of engine data on flight Mach number, pressure recovery, and operating temperature. Possibilities of adapting a ram-jet to variable operating conditions are discussed, and comparison is made between some methods of regulation. In addition, the possibility of combining ram-jets with other propulsive units is discussed.

Rocket

DIE EIGENSCHAFTEN EINIGER LEICHTER ELEMENTE UND IHRER MISCHUNGEN IM HINBLICK AUF IHRE ANWENDUNG ALS ARBEITSGASE IN NICHT KONVENTIONELL BEHEIZTEN RAKETEN. Irene Sänger-Bredt. (NATO AGARD 9th Gen. Assembly, Aachen, Sept., 1959.) Raketentech. & Raumfahrtforsch., Jan.-Mar., 1960, pp. 7-16. 44 refs. In German. Definition of the term "working fluid" and its functions in recent rocket development; survey of various possibilities of heating and then accelerating the working fluids; and presentation of enthalpy-entropy diagrams for certain working gases. These include pure hydrogen, oxygen, mixtures (1 : 1 and 2 : 1) of these two gases, helium, and argon-free air. The diagrams are calculated taking into account all possible dissociations and ionizations at equilibrium conditions over the pressure range from 10^{+1} to 10^{-5} atm. and for temperatures up to 10,000°K. Also derived is the specific impulse which can be reached by heating a working gas to arbitrarily chosen temperatures, followed by purely thermodynamic expansion, in a Laval nozzle at different pressure gradients. The influence of the mean molecular weights and the specific heats of mixtures on the specific impulse is pointed out. In addition, heat transfer to the chamber walls is studied by way of comparison, introducing parameters for the heat transfer by convection and radiation.

ESTIMATE OF CHEMICAL SPACE HEATING RATES IN GAS-PHASE COMBUSTION WITH APPLICATION TO ROCKET PROPELLANTS. Appendix A - EVALUATION OF THE RATIO $\omega_{max}/\bar{\omega}$. Appendix B - HEAT RELEASE CALCULATIONS FOR HYDROGEN, PROPYLENE OXIDE AND ISOPROPYL CHLORIDE IN THE WELL-STIRRED REACTOR. D. A. Bittker and R. S. Brokaw. (ARS Semi-Annual Meeting, San Diego, June 8-12, 1959.) ARS J., Feb., 1960, pp. 179-185. 28 refs. Presentation of a simple, approximate method for calculating maximum chemical space heating rates in combustion processes. The results represent the theoretical maximum possible heat release rate to be expected from a unit volume of a reacting fuel-oxidant mixture. An important purpose of this work is the application of the method to several rocket propellant combinations. Comparison of the results with estimated heat release rates for the same propellants in experimental rocket engines shows that the latter are several orders of magnitude less than the calculated maximum chemical rate for a given propellant.

EXPERIMENTAL INVESTIGATION OF PROPELLANT EROSION. Tage Marklund and Arne Lake. ARS J., Feb., 1960, pp. 173-178. Description of erosion test methods, characterized by separate gas producing charges and separate specimens in the gas stream. The specimens are tablets, strips, and nozzle inserts of composite propellants. Changing the temperature of the gas stream over a propellant specimen from 1,690° to 2,550°K. did not seem to influence the erosion at constant gas velocity and pressure. Erosion at near sound velocity in a propellant nozzle was found to be of the same order of magnitude as on strips at lower gas velocity but the same mass velocity. Results are discussed particularly in view of the Lenoir and Robillard theory of propellant erosion.

THEORY OF LIQUID PROPELLANT ROCKET COMBUSTION INSTABILITY AND ITS EXPERIMENTAL VERIFICATION. Luigi Crocco, Jerry Grey, and D. T. Harrje. (ARS Semi-Annual Meeting, San Diego, June 8-12, 1959.) ARS J., Feb., 1960, pp. 159-168. 15 refs. Navy-sponsored presentation of straightforward theoretical formulation of the longitudinal high-frequency rocket stability criteria. Based on Crocco's sensitive combustion time lag theory, the derivation is considerably simpler, although somewhat less rigorous, than previously published detailed treatments. A series of rocket motor experiments is described, demonstrating that there exists an upper limit to the chamber length at which each mode of longitudinal high-frequency pressure oscillations will occur, and that this limit is accurately predicted by the theory over a wide range of mixture ratios of two different injectors. The method used to compare experimental results with the theoretical stability limit predictions, including a simple experimental technique for determining the sensitive time lag, is described.

EFFECTS OF GAS MOTION ON HETEROGENEOUS COMBUSTION; NATURAL CONVECTION, STEADY FORCED CONVECTION, STANDING ACOUSTIC WAVES, AND SHOCK WAVES FINAL SUMMARY REPORT. Appendix I - CONDITIONS TO BE EXPECTED IN ROCKET ENGINE COMBUSTION. Appendix II - COMPUTATIONS USED TO REDUCE SHOCK TUBE DATA. Appendix III - TEST SUMMARIES. Appendix IV - TABULATIONS OF COMPUTED WAVE PARAMETERS. W. T. Webber. USAF WADC TR 59-50, Apr., 1959. 88 pp. 26 refs. Description of two experimental techniques to determine the effects of gas motion upon the combustion of liquid fuels under extremes of conditions resembling those found in liquid rocket combustion chambers. The quartz-fibre type of apparatus permits absolute values for burning rate per unit of fuel surface to be measured, but cannot be used at extremely high Reynolds numbers where liquid fuel is blown off the fiber. The shock tube apparatus has no obvious Reynolds number limitation, and further, the shock tube permits data to be gathered relative to the rate of response of combustion to very rapid transient changes in conditions. The absolute magnitudes of the heat and mass transport coefficients obtained in the shock tube, however, are at present somewhat in doubt, since the droplet size distribution is not accurately known.

RESEARCH, RESEARCH FACILITIES

Wind Tunnels

SUR QUELQUES PROBLEMES POSES PAR L'EXPERIMENTATION EN SOUFFLERIE AERODYNAMIQUE. André Martinot-Lagarde. France, Min. de l'Air PST 353, 1959. 105 pp. 29 refs. SDIT, 2 Av. Porte-d'Issy, Paris 15, Frs. 1,665. In French. Survey of certain problems encountered in wind-tunnel experiments. Includes description of experimental techniques and methods for interpreting wind-tunnel results; application of the Gouy-Stodola principle of useful energy to wind-tunnel experiments; application of the direct method to the case of similarity of transonic nozzle flows; description of a vertical tunnel for studying spin; and comparison of results obtained on models with flight test data.

STRUCTURES

Bars & Rods

TORSIONAL CREEP BUCKLING OF OPEN TUBES HAVING ARBITRARY CROSS-SECTION. George Lianis. Purdue U. Sch. Aero. Eng. Rep. S-59-1, Dec., 1959. 53 pp. 18 refs. Application of the variational theorem by Sanders, McComb, and Schlechte to find the critical collapse time of a general open tube subjected to torsional creep buckling. Large deformation strains are considered, and it is shown that small deformation strains yield inaccurate results in predicting the critical time. A simplified stress distribution is introduced which gives a closed form solution.

Cylinders & Shells

ON THE STABILITY PROBLEM FOR SHALLOW SPHERICAL SHELLS. Hubertus Weinitschke. J. Math. & Phys., Jan., 1960, pp. 209-231. 21 refs. ONR-sponsored review of previous analyses for determining a stability curve - i.e., the functional dependence of the buckling load on the geometric shell parameter, and presentation of a new analysis to give a more definitive answer to the question of stability with respect to axisymmetric deformations. The validity of series solutions presented is established by means of a detailed study of the convergence of the series. Certain techniques are developed, which are believed to be of principal and practical significance for solving a general class of nonlinear boundary value problems for ordinary differential equations. These methods involve power series expansions of analytic functions at several points of a finite interval. Numerical computations are performed on an IBM computer, and the results show stresses and displacements as functions of a nondimensional polar angle and load deflection curves. From these, the critical loads are determined using the classical stability criterion. Comparison is made with the conclusions reached by Reiss, Greenberg, and Keller, and some reasons for the discrepancies are indicated.

Elasticity & Plasticity

C - ELASTIZITÄT UND PLASTIZITÄT. (GAMM Wissenschaftliche Jahrestagung, Hannover, May 19-23, 1959.) ZAMM, Sept.-Nov., 1959, pp. 411-427. 25 refs. In German and English. Partial Contents: Die Abhängigkeit der Lösung der Elastizitätsprobleme von kleinen Veränderungen des Definitionsgebietes, Ivo Babuška. Zur Integration der Differentialgleichungen für dünne elastische Kreiszylinderschalen auf mehreren Stützen, A. Kuhelj. Der lange, dünne Stab unter konservativer Längskraft und Torsion, H. Leipholz. Beweis des St. Venantschen Prinzips, Matthias Matschinski. Kinetisches Durchschlagen des schwach gekrümmten Stabes, E. Mettler and F. Weidenhammer. Bernoullische Hypothesen bei Balken- und Plattentheorie, Dietrich Morgenstern. Contributions to the Problem of Vibrations of Plates with Damping Considered, Danilo Rašković. A Geometric Derivation of the Non Linear Stress-Strain Relations for Isotropic Elastic Solids, Rastko Stojanovitch. Symposium of papers covering the solution of problems in elasticity; integration of differential equations for thin, elastic circular cylindrical shells; long thin rods subjected to a conservative axial force and torsion; applicability of the St. Venant principle; kinetic stress of lightly curved bars; use of Bernoulli's hypothesis in the theory of beams and plates; vibration of plates, taking into account the effect of damping; derivation of nonlinear stress-strain relations for isotropic elastic solids; and analytical determination of the state of deformation in polymers.

ELASTIC WAVES GENERATED BY A FORCE MOVING ALONG A CRACK. Dang Dinh Ang. J. Math. & Phys., Jan., 1960, pp. 246-256. 10 refs. Navy-supported analysis concerning the stress wave patterns generated by a line load moving along a half-plane crack in an infinite elastic medium and, in particular, with the stress singularities at the edge of the crack and at the front of the Rayleigh surface wave. The load is represented by a delta-function. Although this is an idealization, the solution can be considered essentially as a fundamental one from which solutions corresponding to more general moving forces can be constructed. The method of solution used is Clemmow's version of the Wiener-Hopf method. It is concluded that because of a resonance effect near the Rayleigh wave velocity, this speed is a possible limiting velocity for the propagation of cracks in elastic media.

Plates

THE LARGE-DEFLEXION BEHAVIOUR OF A THIN STRIP OF LENTICULAR SECTION. E. H. Mansfield. Quart. J. Mech. & Appl. Math., Nov., 1959, pp. 421-430. Presentation of a large-deflection solution for a thin strip of lenticular parabolic section subjected to combined moment and torque. A feature of this particular cross section is that the chordwise curvature of the distorted strip does not vary across the chord; this results in a considerable simplification in the analysis and enables the behavior of the strip before and after buckling to be fully investigated. It is also shown that for large values of the applied moments the large-deflection solution approaches that predicted previously by inextensional theory.

Plates, Stiffened

STIFFENED PLATING UNDER TRANSVERSE LOAD. M. Holmes. Quart. J. Mech. & Appl. Math., Nov., 1959, pp. 443-453. Analysis of a plate stiffened with beams by the Fourier series and presentation of solutions for symmetrical and antisymmetrical forms of loading. An alternative method of analysis is derived for symmetrical loading forms, involving the evaluation of the plate efficiency. This alternative method has some advantage in that the applied loading is expressed in the form of a Fourier series for bending moment rather than intensity. Finally, it is shown that approximate solutions (assuming infinite torsional rigidity of the beams) may be obtained for a wide variety of loading forms by superimposing the solutions for the symmetrical and antisymmetrical forms of loading.

PŁYTA ORTOTROPOWA Z CIENKOŚCIENNYMI ŻEBRAMI NIESYMETRYCZNYMI. Piotr Wilde. Rozprawy Inżynierskie, No. 3, 1959, pp. 273-310. 22 refs. In Polish, with summaries in English and Russian. Analysis considering an orthotropic plate having asymmetric ribs constituting a monolithic structure with the plate. Equations are derived for the reactions of the ribs and then, the orthotropic plate is loaded by these reactions. A system of three differential equations is obtained, determining the displacements in the plate with given boundary conditions. The equations take into consideration the inertia forces and describe the buckling problem. The solution for arbitrary ribs is obtained by means of the displacement function in the case of cylindrical loading. The general solution expressed by double trigonometric series is obtained with any boundary conditions by means of the Fourier transformation for a plate with symmetric ribs. The problem of determining the frequency of free vibration and that of buckling of a simply supported or clamped plate are discussed. For a sinusoidal load, an equation for the given width of a ribbed plate with two main girders is obtained.

SHEAR LAG SOLUTIONS FOR SHEET-STRINGER PANELS BY MEANS OF A HYDRODYNAMIC ANALOGY. Martin Goland. J. Aero/Space Sci., Apr., 1960, pp. 291-295, 303. Establishment of an analogy between the stress flow in flat sheet-stringer panels and the plane potential flow of an incompressible fluid. It is shown that the hydrodynamic analogy consists of a direct relationship between longitudinal stress and the longitudinally directed component of fluid velocity. A discussion is given of the corresponding boundary conditions for the stress flow and the fluid flow. A boundary free of normal stress is equivalent to flow past a solid wall. It is also shown how rigidly constrained boundaries can be dealt with in a relatively simple fashion. Problems of reinforcement around cutouts in the sheet-stringer panel are also discussed. The use of the analogy is demonstrated on several examples, including the stress concentration around elliptic cutouts with free and constrained boundaries in large panels under uniform tension. Also studied is the case of a concentrated longitudinal force applied at the center of a large panel.

Plates with Holes

FLEXURAL PROBLEMS OF CIRCULAR RING PLATES AND SECTORIAL PLATES. I. W. A. Bassali and M. A. Gorgui. Cambridge Philos. Soc. Proc., Jan., 1960, pp. 75-95. 18 refs. Development of explicit expressions in closed form for the complex potentials and deflection at any point of a circular annular plate under various edge conditions, when the plate is acted upon by general line loadings distributed along the circumference of a concentric circle. Solutions for singularly loaded sectorial plates bounded by two arcs of concentric circles and two radii are also derived when the plate is simply supported along the straight edges. The boundary conditions along the circular edges include the cases of a free boundary, as well as the elastically restrained boundary, which covers the usual rigidly clamped and simply supported boundaries as special cases. The usual restrictions relating to the small deflection theory of thin plates of constant thickness are assumed.

Thermal Stress

PROCEDURES FOR INCLUDING TEMPERATURE EFFECTS IN STRUCTURAL ANALYSES OF ELASTIC WINGS. II - A DIGITAL COMPUTER SOLUTION FOR THE EQUIVALENT PLATE METHOD OF THERMOELASTIC ANALYSIS. L. A. Schmit and H. A. Balmer. USAF WADC TR 57-754, Pt. II [AD 216084], May, 1959. 158 pp. Presentation of a rational method for analyzing the static aeroelastic behavior of thin, low aspect-ratio wings subjected to elevated temperatures and high wing loadings. The formulation includes coupling between aerodynamic pressures and thermoelastic distortions, and also coupling between the bending and stretching of the plate. Using Reissner's variational principle and expanding the deflection and the stress function in terms of assumed modes, two coupled nonlinear matrix equations are obtained and solved by successive linearization. An IBM 704 computer is used to carry out the considerable number of partial differentiations, double integrations, and algebraic operations required to form the matrix elements.

MEASURING ACCURACY IN CREEP TESTS. II - INFLUENCE OF THERMAL STRESSES. Arne Mellgren. USAF WADC TR 59-78, Pt. II, Oct., 1959. 54 pp. 10 refs. Calculation of the thermal stresses induced in cylinders and plates by nonuniform surface temperatures. The relations of thermal stresses to creep are then determined for cylindrical and sheet creep specimens. These relations are expressed mathematically for sinusoidal and square wave surface temperature gradients. Numerical examples are presented and discussed.

THERMODYNAMICS

Combustion

EXPLOSIONS, DETONATIONS, FLAMMABILITY AND IGNITION. I - SELECTED ANALYTICAL STUDIES ON EXPLOSIONS, DETONATIONS, FLAMMABILITY LIMITS, AND IGNITION OF GASES, AND ON HETEROGENEOUS BURNING. S. S. Penner. II - EXPERIMENTAL AND THEORETICAL STUDIES OF FLAMMABILITY, IGNITIBILITY AND EXPLOSION PREVENTION. B. P. Mullins. NATO AGARDograph 31, 1959. Published for and on behalf of AGARD, NATO, by Pergamon Press, 1959. 287 pp. 682 refs. $10.00; 70 s. Study of problems in flammability and ignition from different viewpoints, part I being analytical and part II semiempirical and practical. The first part includes a summary of aerothermochemical fundamentals and detonation phenomena. Emphasis is placed on the technique introduced into theoretical combustion research by Schvab and Zeldovich. In the second part, a thermal hypothesis, which might be described as a generalization of Semenov's concept of the ignition temperature, is shown to be of great use in predicting combustion phenomena such as flammability limits and flash-points and the effects of diluent gases on limiting combustion processes.

DIFFUSION COEFFICIENTS IN FLAMES AND DETONATIONS WITH CONSTANT ENTHALPY. J. O. Hirschfelder. Phys. Fluids, Jan.-Feb., 1960, pp. 109-112. Navy-supported analysis showing that the assumption of constant enthalpy is equivalent to setting all the coefficients of binary diffusion equal to each other and setting corresponding Lewis numbers equal to unity. In the case of detonations or flames having appreciable kinetic energy, it is also necessary to set the Prandtl number equal to 3/4.

STATISTICAL STUDY OF ACCELERATING FLAMES. R. A. Stern, A. J. Laderman, and A. K. Oppenheim. Phys. Fluids, Jan.-Feb., 1960, pp. 113-120. 12 refs. Study of velocity fluctuations, observed by means of ionization probes during the development of detonation, showing its significance as an indicator of physical characteristics of the flame. The scatter in time of arrival (the reciprocal of the velocity) is found normally distributed at a probability level. The intensity of scatter is interpreted consequently as indicative of the combustion front fluctuation that can be considered to delineate the "effective flame thickness." It is found that, as the flame accelerates, its effective thickness first increases, reaching a maximum in the vicinity of velocity overshoot, and then decreases, attaining finally a minimum, constant value when the steady detonation wave is established. An bimodal distribution of scatter for the $2H_2$-O_2 mixture is observed, indicating a possible existence of two alternative, independent modes for the development of the process.

Heat Transfer

STABILITY OF A HORIZONTAL FLUID LAYER WITH UNSTEADY HEATING FROM BELOW AND TIME-DEPENDENT BODY FORCE. A. W. Goldstein. US, NASA TR R-4, 1959. 15 pp. 12 refs. Supt. of Doc., Wash., $0.30. Analysis that assumes an incompressible fluid with small density changes resulting from heating. The critical Rayleigh numbers, based on the overall density differential are much higher than for the static case, are dependent only on the density distribution and instantaneous value of the acceleration, and are independent of Prandtl number and rate of change of temperature and body force field. The initial motion corresponds to approximately the same cell shape as for the static case. Rate transition of temperature perturbations from a stable to an unstable condition is proportional to the rate of increase of the temperature gradient in the region well removed from the walls; rate of transition of the slow motion is proportional to the Prandtl number and rate of increase of the body force field.

THEORY OF HEAT TRANSFER FROM HOT STEADY OR INTERMITTENT SUPERSONIC JETS. S. T. Demetriades. Northrop ND Rep. NB-59-152, Mar. 16, 1959. 59 pp. 13 refs. Development of approximate formulas for the wall shear and rate of heat transfer to a wall when a steady supersonic jet impinges on surfaces of various geometries. Heat transfer, wall shear, and surface temperatures from an intermittent jet are shown to be less severe. It is shown that, in the limiting conservative case, surface temperature can be reduced by at least 15% in the stagnation region. These results are also true of spinning bodies and steady jets. By spinning a body exposed to hot stagnation conditions, the temperature of its surface can be reduced by significant amounts. The results are applicable to the design of jet deflectors for rocket engines, re-entry bodies, and other similar problems where large reductions of surface temperature are required.

HEAT TRANSFER IN LOW REYNOLD'S NUMBER SLIP FLOW. H. C. Levey. Australia, ARL Rep. A.112, Mar., 1959. 12 pp. Investigation, for small Reynolds numbers, of the heat transfer by forced convection from a hot wire in a low Mach number rarefied gas stream. A simple expression is found for the Nusselt number, and it is suggested that this has reasonable validity over a wide range of Knudsen numbers, even into the free-molecule flow regime.

GRAPHICAL PRESENTATION OF DIFFERENCE SOLUTIONS FOR TRANSIENT RADIAL HEAT CONDUCTION IN HOLLOW CYLINDERS WITH HEAT TRANSFER AT THE INNER RADIUS AND FINITE SLABS WITH HEAT TRANSFER AT ONE BOUNDARY. J. E. Hatch, R. L. Schacht, L. U. Albers, and P. G. Saper. US, NASA TR R-56, 1960. 58 pp. Study of nondimensional temperature distributions for transient radial heat conduction through hollow cylinders and one-dimensional heat conduction in slabs of finite thickness. In both types of conduction it is assumed that the boundary opposite the heat-transfer surface is thermally insulated. The radial solutions cover a range of dimensionless radius ratios. The material is as-

sumed to be homogeneous, and the physical properties are considered invariant with temperature.

VTOL & STOL

A GENERALIZED STUDY OF PROPULSION SYSTEMS FOR VTOL AIRCRAFT. P. W. Pratt, C. B. Smith, T. G. Slaiby, and B. B. Silverman. IAS 28th Annual Meeting, New York, Jan. 25-27, 1960, Paper 60-41. Members, $0.50; nonmembers, $1.00. 45 pp. Study of the characteristics of propulsion systems primarily affecting VTOL performance, and presentation of typical values for the various gas propulsion systems being considered. These include the shaft-driven rotor, pressure jet rotor, lightly loaded propeller, ducted propeller, variable geometry propeller, lifting fan, turbofan, and turbojet. The propulsion characteristics are combined with a simple set of airframe characteristics, and the performance potential is calculated for various propulsive systems over a range of hover times and cruise speeds.

A REVIEW OF THE WING-SLIPSTREAM PROBLEM WITH EXPERIMENTS ON A WING SPANNING A CIRCULAR JET. F. W. Gobetz. Princeton U. Dept. Aero. Eng. Rep. 489, Jan., 1960. 112 pp. 11 refs. ONR-supported evaluation of previous studies on the increase in lift of wings immersed in slipstreams, presentation of new experimental data on the phenomenon, and comparison of these data with the most promising of the theoretical analyses. The correlation between the present data and the theory formulated by Rethorst is quite good and indicated that at least some of the predicted trends are correct. In addition, an integrating manometer employed in the experiments is described.

THE PROPULSION ASPECTS OF GROUND EFFECT MACHINES. R. W. Pinnes. IAS 28th Annual Meeting, New York, Jan. 25-27, 1960, Paper 60-13. Members, $0.50; nonmembers, $1.00. 23 pp. 12 refs. Comparison of some recently available test results with some earlier theoretical predictions and indication of the degree of correlation. Some earlier predictions of GEM potential are modified on the basis of these test data. It is demonstrated that the GEM has a good lift-to-horsepower ratio capability, and suggestions for improving this are discussed. It is also shown that a good selection of engines - both turboprop and reciprocating - is available.

A METHOD OF DESIGN OF SHROUDED PROPELLERS. V. O. Hoehne and R. E. Monical. U. Wichita Dept. Eng. Res. Rep. 213-8, Oct., 1959. 35 pp. ONR-supported presentation of a method for designing shrouded propellers, using previously derived information, developed to design several wind tunnel models. Results of tests of one of the models designed by these procedures are compared with predicted data to establish the validity of the method. The comparison shows that this system of design predicted performance within the range of normal design accuracy. Predicted efficiency is several percentage points lower than achieved efficiency.

DER BODENEFFEKT ALS ENTWICKLUNGS-GRUNDLAGE VON SCHWEBEGERÄTEN. K. W. Mack. Luftfahrttechnik, Jan. 10, 1960, pp. 5-21. 33 refs. In German. Discussion of the ground effect principle as the basic concept for the design of hovercraft. It is shown that the ground effect depends on a number of parameters and changes from the positive effect (increase in thrust) to a negative effect (thrust loss) in connection with the jet pattern. A survey is made of the development of hovercraft based on the ground effect - i.e., both the actual air-cushion vehicles and the related aerial jeeps, and future possibilities are evaluated. The most important features of some models under construction or in the design stage are evaluated along with some future requirements.

SHROUDED PROPELLER INVESTIGATIONS. I - WIND-TUNNEL TESTS OF A SHROUDED PROPELLER WITH A 17-BLADED ROTOR, INLET AND EXIT STATORS, AND LONG SHROUD WITH HIGH-SPEED INLET AND NO EXIT DIFFUSION. II - WIND TUNNEL TESTS OF A SHROUDED PROPELLER WITH A 17-BLADED ROTOR, INLET AND EXIT STATORS, AND LONG CHORD SHROUD WITH STATIC INLET AND NO DIFFUSION. III - WIND TUNNEL TESTS OF A SHROUDED PROPELLER WITH A 17-BLADED ROTOR, INLET AND EXIT STATORS, AND LONG CHORD SHROUD WITH MODIFIED STATIC INLET AND NO DIFFUSION. IV - STATIC PERFORMANCE OF TWO HIGHLY-LOADED SHROUDED PROPELLERS AS MEASURED IN THE WALTER H. BEECH MEMORIAL WIND TUNNEL. V - WIND TUNNEL TESTS OF A SHROUDED PROPELLER WITH A 10-BLADED PROPELLER, EXIT STATORS, AND LONG CHORD SHROUD WITH HIGH SPEED INLET AND NO EXIT DIFFUSION. VI - WIND TUNNEL TESTS OF A SHROUDED PROPELLER WITH A 10-BLADED PROPELLER, EXIT STATORS, AND LONG CHORD SHROUD WITH STATIC INLET AND NO DIFFUSION. VII - WIND TUNNEL TESTS OF A SHROUDED PROPELLER WITH A 10-BLADED PROPELLER, EXIT-STATORS, AND LONG CHORD SHROUD WITH A MODIFIED STATIC INLET AND NO DIFFUSION. IX - SHROUD AND CENTERBODY PRESSURE DISTRIBUTIONS OF A SHROUDED PROPELLER WITH A 17-BLADED ROTOR, INLET AND EXIT STATORS AND LONG CHORD SHROUD. X - SHROUD AND CENTERBODY PRESSURE DISTRIBUTIONS OF A SHROUDED PROPELLER WITH A 10-BLADED ROTOR, EXIT STATORS AND LONG CHORD SHROUD. V. O. Hoehne and R. K. Wattson, Jr. U. Wichita Dept. Eng. Res. Eng. Reps. 213-1; 213-2; 213-3; 213-4; 213-4; 213-5; 213-6; 213-7; 213-9; 213-10, June; Sept., 1958; Jan.; Oct., 1959; Jan., 1960. 64; 77; 71; 49; 48; 64; 66; 97; 52 pp. 52 refs. Navy-supported presentation of a series of reports describing the performance characteristics of a family of shrouded propellers, covering a wide range of design variables, operated under conditions of varying freestream airspeed, propeller rotational speed, and angle of attack.

tem requirements and design possibilities. Jet-flap control to 100,000 ft., reaction jets, controllable turbojet nozzles, and vernier control systems for operation in the atmosphere and in space are discussed.

Guidance and Navigation Designers Scramble to Meet Space Needs. *Electronic Des.*, Jan. 20, 1960, pp. 4–11. Discussion of progress being made in inertial, celestial, radio, and Doppler navigation systems.

Effect of Thrust Misalignment on Gyro-Stabilized Vehicles. R. P. Nagorski. *ARS J.*, Jan., 1960, pp. 128,129. Development of analytical expressions which effect the flight profile due to thrust misalignment.

On the Long Periodic Lateral Motion of a Beam Riding Missile Toward Its Center Line. Syoiti Tsuji. *Japan Soc. Aero. & Space Sci. J.*, Nov., 1959, pp. 293–296. In Japanese. Presentation of a method for solving complex beam riding characteristics of a missile. It deals with the slow lateral behavior of a missile toward beam centerline, and a simplified equation of motion is derived.

Solid-State Guidance for Able-Series Rockets. R. E. King and Henry Low. *Electronics*, Jan. 29, 1960, pp. 60–63. Description of the control circuit for the second stage which makes the missile follow a predetermined course in response to commands generated by an internal programer, or in response to guidance commands from the ground.

Spacecraft

Review, Scope and Recent Results of Project Mercury Research and Development Program. A. C. Bond and A. B. Kehlet. *IAS 28th Annual Meeting, New York, Jan. 25–27, 1960, Paper 60-35.* Members, $0.50; nonmembers, $1.00. 15 pp. Discussion and evaluation of several research programs considering the design concepts, operational spectrum, and requirements for a capsule capable of executing the Mercury mission profile.

Review of the Operational Plans for Mercury Orbital Mission. Ch. W. Mathews. *IAS 28th Annual Meeting, New York, Jan. 25–27, 1960, Paper 60-36.* Members, $0.50; nonmembers, $1.00. 11 pp. Presentation of the capsule preparation and launch, monitoring, control, and recovery plans for the manned space vehicle.

Mercury Capsule and Its Flight Systems. M. A. Faget and R. O. Piland. *IAS 28th Annual Meeting, New York, Jan. 25–27, 1960, Paper 60-34.* Members, $0.50; nonmembers, $1.00. 15 pp. Detailed description of the capsule and its various on-board systems, and presentation of the sequence of important flight events for the normal mission. The environmental control system, the attitude control, the communication, and the power supply systems are described.

Plane Libration of a Prolate Ellipsoidal Shell. R. M. L. Baker, Jr. *ARS J.*, Jan., 1960, pp. 126–128.

Librations on a Slightly Eccentric Orbit. R. M. L. Baker, Jr. *ARS J.*, Jan., 1960, pp. 124–126. Analysis showing that the motion of a satellite about a position of stable equilibrium is a solution to Mathieu's equation with an amplitude in radians less than, or equal to, the orbital eccentricity.

Satellite Librations of Large Amplitude. W. B. Klemperer. *ARS J.*, Jan., 1960, pp. 123, 124. Presentation of a simplified differential equation of motion of a dumbbell-shaped instrument that is carried aboard the satellite and allowed to swing in the plane of the orbit.

Projected Orbits of 24-hr Earth Satellites. L. B. Wadel. *ARS J.*, Jan., 1960, pp. 122, 123. Calculations of a "figure 8" path in terms of latitude and longitude as a function of the angle made by the satellite's orbital plane with the earth's equatorial plane. If this path angle is zero, the path reduces to a single point on the equator.

Graphic Solution of Some Earth Satellite Problems by Use of the Stereographic Net. R. E. Wallace. *Brit. Interpl. Soc. J.*, Sept.-Oct., 1959, pp. 120–123. Application of the stereographic net, which is an equatorial plot of a hemisphere incorporating great and small circle coordinates, as a basis for plotting and graphically solving orbit problems. Plotting of features such as trace of orbit, precession of orbit, pass times, and limits of Earth shadows permits measurement of relations between different components of the problem.

Lunar and Solar Perturbations on Satellite Orbits. E. Upton, A. Bailie, and P. Musen. *Science*, Dec. 18, 1959, pp. 1710, 1711. Calculations of the solar and lunar effects on highly eccentric satellite orbits showing that the sun and the moon may cause large changes in perigee height over extended periods of time. The amplitude and sign of perigee height variations depend on the orbit parameters and the hour of launch.

Lockheed Discoverer Project. *The Aeroplane & Astronautics*, Jan. 1, 1960, pp. 21, 22. Presentation of design characteristics of the system and brief history of the project.

Geophysical Research Using Artificial Earth Satellites. J. F. Clark. *IAS 28th Annual Meeting, New York, Jan. 25–27, 1960, Paper 60-50.* Members, $0.50; nonmembers, $1.00. 7 pp. Presentation of the geophysical satellite results, exploring the nature of the control exerted by the sun over events on the earth. Planned future efforts in this area are discussed.

Astronomical Measurements with Rockets, Satellites and Balloons. A. P. Willmore. *Brit. Interpl. Soc. J.*, Sept.-Oct., 1959, pp. 137–140. Review of the development in high-altitude astronomy during the last decade.

Project Echo Satellites to be Orbited from Pacific Missile Range. *Western Av.*, Dec., 1959, pp. 10, 11. Discussion of the planned experiment using two giant balloon satellites launched into polar orbits. Tracking procedures and details of the coast-to-coast communications system are presented.

Navigation

Contribution to the Theory of Inertial Damped Systems with Arbitrary Period, Invariant with Respect to Maneuvering of the Object. V. A. Bodner, V. P. Seleznov, and V. E. Ovcharov. (*AN SSSR Otd. Tekh. Nauk Izv. Energ. i Avtom.*, May-June, 1959, pp. 11–18.) *ARS J. Suppl.*, Jan., 1960, pp. 93–97. 15 refs. Translation. Presentation of the theory and principles of construction of damped inertial systems with arbitrary period, insensitive to acceleration with respect to the maneuvering of the object. A theorem is formulated which is a generalization of the corresponding theorem by Schuler.

Electronic Transmission of Aeronautical Charts. J. D. Kay. *Navigation*, Summer, 1959, pp. 390–395. Description of a proposed system for electronic transmission of aeronautical charts.

Electronic Aids

Global Navigation Display. R. H. Courtney, Jr., Milton Goldin, and M. M. Risdon. *Navigation*, Summer, 1959, pp. 358–364. Development of display technique utilizing a point source lamp for projection through an optical quality globe to create a continuous cartographic display. The globe is gimballed on four axes to provide the capability of either command or slave operation of the display when it is used in conjunction with an automatic navigational computer.

An Extension of the Geographical Coordinate System as Applied to Automatic Ground Position Computation. G. B. Shoemaker. *Navigation*, Summer, 1959, pp. 370–373.

Space Coordinate Transformation Using High-Precision Resolvers. G. H. Steinberg. *Electronic Des.*, Apr. 29, 1959, pp. 24–27. Study showing how resolvers are combined to transform velocity vectors and angles from one coordinate system to another.

Traffic Control

ATCRBS—Air Traffic Control Radar Beacon System. G. E. Kewer. *J. Air Traffic Control*, Jan., 1960, pp. 10–12.

Nuclear Energy

A Simple Explanation of Radiation Damage in Metals. Donald Peckner. *Materials in Des. Eng.*, Jan., 1960, pp. 89–93. 20 refs. Discussion covering the occurrence of radiation, its effects on metal properties, and measures to be taken.

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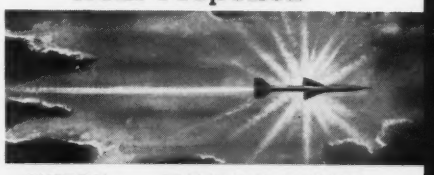

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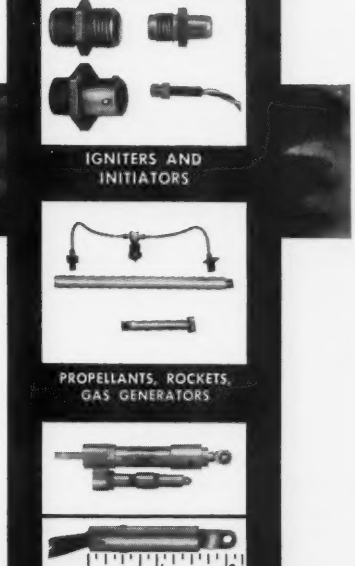

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Parachutes

Some Observations on Supersonic Stabilization and Deceleration Devices. J. F. Connors and J. C. Lovell. *IAS 28th Annual Meeting, New York, Jan. 25–27, 1960, Paper 60-19.* Members, $0.50; nonmembers, $1.00. 15 pp. Study of the stability and drag characteristics of flexible and rigid ribbon-type parachutes and of symmetrical bluff-shape inflatable balloons, as determined in supersonic wind-tunnel investigations at Mach numbers up to 4.0. The actual operation of these devices is demonstrated, and the associated aerodynamic problems are discussed.

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Jet & Turbine

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Ram-Jet & Pulse-Jet

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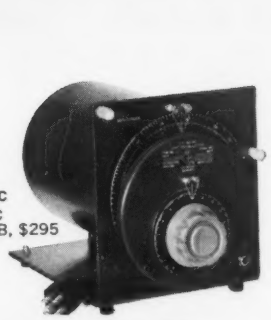

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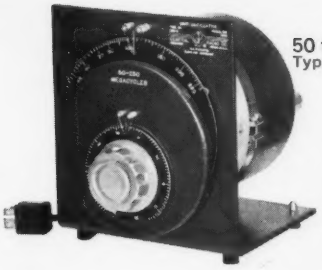

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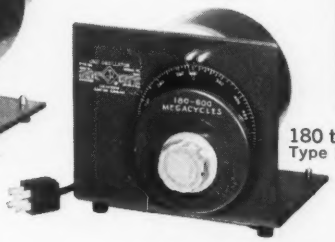

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By merely substituting basic oscillator units in this system, you can cover, in narrow or wide sweeps, segments of the frequency range from 500 kc to 2000 Mc. More than this, you can control sweep speed, center frequency and frequency span over wide ranges by simple knob adjustments.

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Write For Complete Information

★ Sweep Drive's claw-like arm attaches to knobs and dials up to 4 inches in diameter, and to ¼- and ⅜-inch shafts to convert oscillators, signal generators, and receivers to sweep operation.

★ Sweep-speed, sweep-arc, and sweep-center frequency are completely adjustable even while the Drive is in motion.

★ Wide range of sweep speeds... reciprocating motion, adjustable from 0.5 to 5 cps.

★ Sweep arc adjustable from 30° to 300°. At sweep speeds below 1 cps, arc can be increased by coupling Drive directly to Oscillator dial rather than to control Knob attached to vernier reduction-drive.

★ Rated maximum torque is 24 ounce-inches. Limit-switch circuit disconnects and brakes motor should limits of shaft travel be accidentally exceeded.

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Letters

(Continued from page 6)

Acceleration Normal to Flight Path

$$G_2 = F_e \sin \alpha - mg \cos \gamma_1 + mV_a(\dot{\theta} - \dot{\gamma}_1) = 0 \quad (3)$$

Vertical Velocity

$$G_3 = \dot{h}_a - V_a \sin \gamma_1 = 0 \quad (4)$$

Horizontal Velocity

$$G_4 = h_a\dot{\theta} - V_a \cos \gamma_1 = 0 \quad (5)$$

These equations apply to flight *in vacuo*, and in this case the rocket thrust $F_e(t)$, like the mass $m(t)$, is a prescribed function of time. The acceleration of gravity g is taken in reference 1 as the inverse square law variation with altitude given by

$$g = g_0(R_e/h_a)^2 \quad (6)$$

In a proper application of the multiplier rule for subsidiary conditions which are differential equations, variable multiplier functions λ_1, λ_2, λ_3, and λ_4 are introduced, and the integral

$$\int_{t_1}^{t_2} F\,dt = \int_{t_1}^{t_2} [V_a \sin \gamma_1 + \lambda_1 G_1 + \lambda_2 G_2 + \lambda_3 G_3 + \lambda_4 G_4]\,dt \quad (7)$$

is then made stationary with respect to the functions V_a, γ_1, h_a, θ, and α. A necessary condition for a stationary value of the integral is that the Euler-Lagrange equations

$$\frac{d}{dt}\left(\frac{\partial F}{\partial(dx_i/dt)}\right) - \frac{\partial F}{\partial x_i} = 0 \quad (8)$$

where $i = 1, \ldots 5$ be satisfied. There will be five such equations, corresponding to $x_1 = V_a$, $x_2 = \gamma_1$, $x_3 = h_a$, $x_4 = \theta$, and $x_5 = \alpha$.

These equations, together with Eqs. (2) through (5), serve to determine the functions x_i and the λ multipliers. This matter is discussed in a number of texts—for example, in those of Courant and Hilbert[2] and Bliss.[3] Quite a number of papers over the years have correctly developed the Euler-Lagrange equations for optimal flight in the vertical plane; a few of these are listed as references (4) through (11).

There is, of course, nothing sacred about the form of the equations of motion, (2) and (3), and the kinematic relations, (4) and (5), employed above. The question of elimination of variables is of particular interest in a critical appraisal of the Dommasch-Barron analysis.

In the analysis of reference 1, the variable α is (in essence) eliminated between Eqs. (2) and (3). Such an elimination is legitimate, if awkward.

Since there is no explicit dependence upon the variable θ in Eqs. (2) through (5), the elimination of $\dot{\theta}$ between Eqs. (3) and (5) is permissible. If no restriction on the range traversed appears in the statement of the boundary conditions, no complications will arise from this elimination.

With the two eliminations performed, the set of Eqs. (2) through (5) takes the following form:

$$g_1 = F_e \cos\left\{\arcsin\left[\frac{m}{F_e}\left(g \cos \gamma_1 + V_a\dot{\gamma}_1 - \frac{V_a^2}{h_a}\cos \gamma_1\right)\right]\right\} - m\dot{V}_a - mg \sin \gamma_1 = 0 \quad (9)$$

$$g_2 = \dot{h}_a - V_a \sin \gamma_1 = 0 \quad (10)$$

The proper development of the Euler-Lagrange equations for the maximum problem, as stated with Eqs. (9) and (10) as subsidiary conditions, requires the introduction of *two* Lagrange multipliers, Λ_1, Λ_2, and the formation of the integral

$$\int_{t_1}^{t_2} \bar{F}\,dt = \int_{t_1}^{t_2} [V_a \sin \gamma_1 + \Lambda_1 g_1 + \Lambda_2 g_2]\,dt \quad (11)$$

Since the integral depends on *three* functions—$x_1 = V_a(t)$, $x_2 = \gamma_1(t)$, and $x_3 = h_a(t)$—three Euler-Lagrange equations

$$\frac{d}{dt}\left(\frac{\partial F}{\partial(dx_i/dt)}\right) - \frac{\partial F}{\partial x_i} = 0 \quad (12)$$

where $i = 1, 2, 3$ must be satisfied along a maximum altitude trajectory in addition to Eqs. (9) and (10).

In the treatment of Dommasch and Barron, no account is taken of Eq. (10) as a subsidiary condition of the extremum problem. Only one multiplier variable (instead of the required two) is introduced. No Euler-Lagrange equation corresponding to the function $x_3 = h_a(t)$ is written.

The fact that Eq. (10) is later used for the numerical determination of trajectories is not relevant to the matter of optimization technique.

Because the effect of the integral of the altitude h_a is ignored in the application of calculus of variations to this problem, the trajectories generated using the analysis of reference 1 are not in any sense optimal.

Henry J. Kelley, AFIAS
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Grumman Aircraft Engrg. Corp.
Bethpage, L.I., N.Y.

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Mr. Dommasch Replies

■ The following refers to Kelley's Letter to the Editor commenting upon our paper "Optimum Rocket Trajectories."

It is our belief—on reading Kelley's own paper (his reference 11), as well as his letter—that he has unduly restrained the variational integrand with the result that he has obtained a subclass of solutions which may be too restrictive. The extraneous restraints which he utilizes seem to be introduced by an improper physical analysis of the problem. This can be shown as follows:

The physical problem under discussion has but two degrees of freedom, and therefore all parameters are expressible in terms of these freedoms, and these freedoms only. Thus the equation

$$\dot{h}_a = V_a \sin \gamma_1$$

does not introduce a new freedom of the system but, on the contrary, constitutes a kinematic definition which is the basis for solving the problem in the first place. Moreover, the integrand to be extremized is obtained directly from this kinematic relation—i.e.,

$$h_a = \int_1^2 \dot{h}_a dt = \int_1^2 V_a \sin \gamma_1 dt \quad (1)$$

is the same statement as $\dot{h}_a = V_a \sin \gamma_1$. It is evident that our problem is therefore constrained to satisfy the relation $\dot{h}_a = V_a \sin \gamma_1$ at the outset, and the double introduction of this definition can serve no purpose.

Any imposed restraint merely serves to limit the class of optimum solutions to some subset which uniquely satisfies the restraint, and therefore the use of restraints does not ensure a general optimum solution but, on the contrary, limits the solution domain. Thus variational techniques (if they are applied to solvable problems) will always produce an optimum answer to the problem designated even if the problem is unreal. A very simple example serves to illustrate this.

With the recognition that extrema of Eq. (1) contain both maxima and minima solutions, and with the further recognition that this equation without restraint is unbounded in V_a but is bounded in γ_1, we may legitimately ask the question, "For a given V_a, what γ_1 should be used to achieve maximum height in a given time?" Without using variational techniques, it is apparent that the answer is to set $\gamma_1 = 90°$, and the proof that even unrestrained integrals provide the proper variational answer is obtained by demonstrating that this answer is actually obtained variationally. Since γ_1 is our only freedom (V_a being fixed), there is only one Euler relation:

$$\frac{d}{dt}\frac{\partial(V_a \sin \gamma_1)}{\partial \dot{\gamma}_1} - \frac{\partial(V_a \sin \gamma_1)}{\partial \gamma_1} = 0$$

(Continued on page 113)

Comet experience which were operating at optimum altitudes, it was considered that provision for off altitude operation of a few thousand feet was adequate allowance for the 707 flights. The imposition of somewhat higher fuel reserves in terms of holding time and debarring of drift up climb paths as compared to the Comet operation were some of the conservatisms introduced, and it was considered that the size had been conservatively picked to do the agreed upon mission. Needless to say, during the period between the ordering of the 707's and their introduction into service, the environment changed quite radically. The first problem encountered was that of the performance regulations under which the airplane would have to operate. The greater loss in performance of the turbojet engine as compared to the piston engine was realized, and P&W was requested to provide a take-off rating for the JT3C essentially independent of temperature over practical limits. This was done with the "C-6" rating up to 90°F., and it was believed that the temperature accountability problem had been satisfactorily solved where it was most important, on take-off, at least as far as engine power was concerned. However, on the basis of experience with turbine-powered aircraft as they began to fly in commercial form special regulations, the SR-422 series became applicable for all turbine-powered transports. The initial SR-422 applied full temperature accountability throughout the flight regime and substituted gradient-of-climb for rate-of-climb requirements; subsequent revisions differed mainly in their effect on runway length. With these regulations the prediction of take-off runway length required on the basis of past experience was ruled out, and the payload for critical long flights became a matter of some concern. While the final regulations are considered quite suitable for the present airplanes, radically different airplanes such as supersonic transports would require quite different regulations, and the resolution of this problem is considered of major significance in the event of planning for their introduction.

The increase in congestion has resulted in ground control of air space both on the airways and at airports. While necessary to handle the traffic, these have resulted in increased flight lengths on fixed routes and greater off-optimum altitude operation. In addition, failure of local surveillance radar may make necessary considerably longer departure paths.

Anti-noise departure patterns and wholesale blocking off of altitudes by the military for various tactical maneuvers were also not anticipated in early planning.

The result of all these factors has been a decrease of some 20 per cent in the practical range of the airplane. They have absorbed all the conservatism considered in sizing the airplane, thus reducing its efficiency, particularly on longer ranges.

Capt. Frank A. Nusom, USN, speaker at the January 12 Wichita Section meeting.

In contrast, one factor which turned out far in excess of expectations was passenger acceptance, although the resulting near-capacity loads aggravated the take-off and anti-noise problems.

As the problems became apparent, concern was felt over the ability to provide the service anticipated with the 707. Studies were made in an effort to predict operating statistics with defined probability distributions for various operational factors. The conclusion was that 15 seats would have to be blocked from the coach section until operating experience justified their presale. In view of the reduction in revenue from this action a more realistic paper evaluation was considered necessary. Resort was made to a Monte Carlo approach—programming all the variables according to the indexing system and selecting by random numbers of typical operating situations. Some 30 situations were developed in this fashion, and the predicted flight statistics have been shown to be amazingly similar to actual flight results. Analysis of the discrepancies that do exist has shown that both ground and air delays are almost entirely responsible. Analysis of payload capacity for these situations was made and criteria established to predict committed loads. On the basis of this analysis the 15-seat restriction was removed before inauguration of service. Service experience has justified this method of analysis; its use would be of considerable benefit in future evaluations of operations with a radically different aircraft.

In the economic planning for the aircraft the costs per hour were predicted quite well, however in the area of block speeds and payloads, estimation would be improved by the use of methods similar to those noted above for committed loads.

In conclusion, Mr. Kolk commented that some decisions would have been made differently if present knowledge had been available, but the overall industry results in introducing the 707 into service had been remarkable.

During the question period considerable discussion centered around airport ground delays at major terminals. Mr. Kolk noted that this situation has not improved; these delays were estimated on the basis of DC-7 experience and due to peaks "on the hour" 707 flight departures were scheduled "off the hour"—"over the dead bodies of the sales people." Delays were and are still higher than estimated with Idlewild being the worst. Idlewild's greater delays are due to factors such as airport layout, longer take-off checks for overseas take-offs, problems relating to obtaining ATC clearances in the high density routes, and traffic volume. In addition jets taking off on the jet take-off runway at Idlewild have to turn into the instrument approach pattern. With respect to the effect of safety of anti-noise departures, Mr. Kolk stated that if safety is adversely affected, take-offs are not made, however, requests to make unsafe maneuvers such as steep turns on breaking ground have been made. Compromises have resulted in longer flight paths.

HAROLD ANDREWS
Secretary

Wichita Section

Naval Research Projects

"Naval Research in Aeronautics" was the topic of the evening when **Capt. Frank A. Nusom,** USN, Asst. Chief for Research of the Office of Naval Research, addressed the January 12 dinner meeting.

Captain Nusom summarized briefly the history of the Office of Naval Research since its inception at the end of World War II and enumerated the fields of research in which ONR performs or sponsors work. He then discussed at some length three examples of specific projects within these fields.

The first was the high-altitude free-balloon program for astrophysical research, in which detection of such things as the composition of planetary atmospheres can be carried out to far greater accuracy with balloon-mounted telescopes and spectrometers than with ground-based instrumentation. The second was the contact-analog cockpit display program, which analyzed the information requirements for operators of a variety of transport vehicles and evolved optimum displays of orientation, director, and quantitative information for which machinery is now being developed. The third example was the ground-effect-machine research which is being conducted by some eleven universities and manufacturers, in an effort to produce, within a year's time, enough experimental and theoretical information to allow evaluation of air-cushion craft as naval vehicles for several applications.

Captain Nusom's discussion was illustrated with slides and motion pictures.

ROBERT K. WATTSON, JR.
Secretary

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REVIEWS OF *Books*

. . . in the field of aeronautical engineering and space technology

AERODYNAMICS

Handbook of Supersonic Aerodynamics; Vol. 5, Section 16, Mechanics of Rarefied Gases. Samuel A. Schaaf and Lawrence Talbot. Produced and Edited by the Aerodynamic Handbook Staff, Applied Physics Laboratory, The Johns Hopkins University, for the Bureau of Ordnance, Department of the Navy. (NAVORD Report 1488, Vol. 5, Sect. 16.) Washington, Supt. of Documents, Feb., 1959. 83 pp., diagrs. $1.25.

This section presents quantitative information of interest to the designer working with the problems of flight at very high altitudes. The topics proper to the mechanics of rarefield gases have been consolidated in a single section of the *Handbook* because the dominant phenomena and theoretical approaches are different from those found in continuum aerodynamics. This particular study is restricted in the range of Mach numbers; therefore the effects of changing specific heat, dissociation, etc., are not considered. For cases of slip flow and free molecular flow, lift, drag, and heat-transfer data for typical bodies are presented in the form of calculations and experimental results. Also, the various flow regimes of rarefied gas dynamics are discussed and defined.

The authors are associated with the University of California, Berkeley.

AERONAUTICS, GENERAL

Advances in Aeronautical Sciences. Proceedings of the First International Congress in the Aeronautical Sciences, Madrid, September 8–13, 1958. Held under the Auspices of the International Council of the Aeronautical Sciences. Editorial Committee: Th. von Kármán, A. M. Ballantyne, H. Blenk, R. R. Dexter, H. L. Dryden, and M. Roy. London, Paris, New York, Pergamon Press, 1959. 2 Vols. 1144 pp., illus., diagrs., tables. £10, $30 the set.

Contents: Some Significant Developments in Aerodynamics Since 1946, Th. von Kármán. Aerodynamic Design for Supersonic Speeds, R.T. Jones. Telecommand and Navigation, W. H. Stephens. Propulsion Supersonique par Turboréacteurs et par Statoréacteurs, M. Roy. Newtonian Flow Theory in Hypersonic Aerodynamics, W. D. Hayes. Dynamics of a Dissociating Gas, M. J. Lighthill. Experimental Investigation of Hypervelocity Flight, J. Lukasiewicz. Buckling and Post-Buckling Behavior of Thermally Loaded Skin Panels, A. van der Neut. Some Contributions to the Heat Conduction and Thermal Stresses Analysis in Aircraft and Missile Structures, L. Broglio. Représentation d'un Système Thermoélastique Vibrant sans la Direction de la Vibration, R. Mazet. Aerodynamic Derivatives for Oscillating Three-Dimensional Wings in Transonic Flow, M. T. Landahl. Mass Transfer Cooling, a Means to Protect High Speed Aircraft, E. R. G. Eckert. Features of Hypersonic Heat Transfer, R. J. Monaghan, L. F. Crabtree, and B. A. Woods. Echanges de Chaleur dans les Ecoulements Presentant des Decollements, J. J. Bernard and R. Siestrunck. Wärmeübertragung bei natürlicher Konvektion, insbesondere durch Stoffe in der Nähe ihres kritischen Zustandes, E. Schmidt. Movimiento Diabático de un Gas en un Conducto Giratorio, J. M. de Sendagorta. Progress in Jet Engine Noise Reduction, F. B. Greatrex and D. M. Brown. Noise Research in Canada: Physical and Bio-Acoustic, K. K. Neely, B. Etkin, and H. S. Ribner. Noise in Air Transport, W. Littlewood. Quelques Etudes sur l'Action Produite par les Jets de Réacteurs sur les Structures, H. J. L. Le Boiteux and P. A. Lienard. Some Considerations of Safety in Automatic Flight Control, A. M. A. Majendie. Auswanderungserscheinungen an schwingenden Kreiseln in kardanischer Lagerung, K. Magnus. Principles of Inertial Guidance, C. S. Draper, W. Wrigley, and R. B. Woodbury. Einige neuere Ergebnisse über Grenzschichtbeeinflussung, H. Schlichting. Fundamental Design Problems of Aircraft with Boundary Layer Control for Maintaining Laminar Flow, G. V. Lachmann. Contribution Théoretique et Experimentale à l'Etude du Contrôle de la Couche Limite par Soufflage, P. Carrière, E. Eichelbrenner, and Ph. Poisson-Quinton. The Use of Boundary-Layer Control to Establish Free Stream-Line Flows, D. G. Hurley. Aeroelastic Problems on Aircraft Construction, H. G. Küssner. A Review of Some Recent Developments in Hypersonic Flow, A. Ferri. Problèmes de l'Aile Annulaire Résolus par Analogie Rhéoélectrique, L. Malavard and G. Hacques. Einige Ergebnisse aus der Theorie des Ringflügels in inkompressibler Strömung, J. Weissinger. A Contribution to the Solution of Mixed Problems of Transonic Aerodynamics, A. A. Dorodnytsin. Research on VTOL and STOL Aircraft in the United States, J. P. Campbell. Safety and Reliability Aspects of VTOL, D. Keith-Lucas. Mécanique de Vol du Propulseur Volant à Décollage et Atterrissage Vertical, G. Eggers and G. Ernst. Structures and Materials for Finite Lifetime, N. J. Hoff. Problems in Heat-Resisting Materials for High-Speed Flight and Propulsion, P. Duwez. Heat Resistant Materials: A Survey of Some British Developments, D. A. Oliver. Telecontrol and Telemetry for Pilotless Aircraft, R. A. Leslie and P. O. Gillard. Transmission of Data by Radio from U.S. Satellites, J. T. Mengel. Prospects and Limitations of Human Flight Beyond the Atmosphere, J. E. Ward and D. G. Simons. Disorientation in Flight, G. M. Jones. Les Limites des Possibilités Humaines dans les Concepts Actuels du Vol et de l'Avion, E. Evrard. Propulsion Methods in Astronautics, W. E. Moeckel. The Physical Basis of Magnetohydrodynamics, W. B. Thompson. A Comparison of Two Approaches to an Electric Propulsion System, V. H. Blackman.

Jane's All the World's Aircraft, 1959-1960. Compiled and Edited by Leonard Bridgman. Asst. Compiler, John W. R. Taylor. New York, McGraw-Hill Book Co., Inc., 1959. 573 pp., illus., diagrs., tables. $32.50.

With this edition *Jane's* celebrates its fiftieth birthday, and so a certain amount of space has been set aside for some things that do not have anything to do directly with the current volume. In the Preface Leonard Bridgman, editor since 1940, writes of Fred T. Jane and Charles G. Grey, who succeeded Jane as editor in 1916. Oliver Stewart, editor of *Aeronautics*, contributes an appreciation of the three editors who created or carried on the monumental task of recording all of the world's aircraft through the embryo years of aviation and two world wars. A chronology of aviation as it was in 1909 (the year in which *Jane's* first appeared) is appended, and reproductions of some pages from the first edition follow the main text.

This year, the aeroplane section exceeds 400 pages and contains 860 illustrations, of which 499 are new. The aeroengine section, which now contains the former gas turbine and piston engine subsections, runs to 97 pages with much new and additional information, including 171 illustrations of which 96 are new. The sections devoted to military aircraft markings and the airlines of the world have been dropped. The third principal section, on guided missiles, totals 50 pages and contains 94 illustrations (59 new), including photographs of Russian research rocket payload containers. Also this year *Jane's* describes and illustrates a large number of American home-built and baby racing airplanes. The index section includes references to all the aircraft and engines described in the ten previous editions of *Jane's*, going back to and including the 1949-1950 edition.

Aircraft and Missiles. D. M. Desoutter. London, Hertford and Harlow; New York, John De Graff Inc., 1959. 213 pp., illus., diagrs., tables. $7.50.

A comprehensive guide and reference work for the general reader, which covers current theory and practice in the fields of aeronautics and aerospace technology. It is largely based on the author's earlier work, *All About Aircraft*.

DICTIONARIES

Aerospace Glossary. Woodford Agee Heflin, Editor. (Air University Documentary Research Study AU-282-58-RSI.) Maxwell AFB, Ala., Research Studies Institute, Air University, Sept., 1959. 115 pp.

This glossary of more than 2,000 terms contains words and phrases spoken by people engaged in aerospace research, development, and operations at the Air University, in the missile industry, and at AF centers, and also those terms found in the current periodical and book literature of missiles, astronautics, and related fields. No attempt has been made to cover the aerospace vocabulary already set forth in the *United States Air Force Dictionary* (1956). The glossary attempts only to describe and expain usage, not to prescribe it.

Guide to the Space Age. Compiled and Edited by C. W. Besserer and Hazel C. Besserer. Englewood Cliffs, N.J., Prentice-Hall, Inc., 1959. 320 pp., diagrs., tables. $7.95.

The purpose of this volume is twofold: (1) to standardize the specialized language associated with missiles and rockets—e.g., propulsion, guidance, control, aerodynamics, structures, electronics, meteorology, and atmospherics—and (2) to present the language in a form easily understood by both technical and lay persons. It contains more than 5,000 definitions, which are alphabetized and cross-referenced, and also figures and tables where they serve to clarify descriptions or concepts.

Mr. Besserer is with Space Technology Laboratories, Inc.; Mrs. Besserer has served as a communications supervisor in the Applied Physics Laboratory, The John Hopkins University.

ELECTRONICS

Telemetering Systems. Perry A. Borden and Wilfrid J. Mayo-Wells. New York, Reinhold Publishing Corp., 1959. 349 pp., illus., diagrs., tables. $8.50.

The present work is a successor to *Principles and Methods of Telemetering*, written in 1948 by P. A. Borden and G. M. Thynell. Emphasis is placed chiefly on types and principles rather than on commercially available equipment. The possibilities of both stationary and mobile telemetering are explored, and the similarities between the two methods are stressed in order to point out their increasing mutual dependencies in regard to practices and techniques. Two features occurring in the original book have been omitted—the list of patents in the general field of telemetering and the bibliography.

P. A. Borden is a registered professional engineer and Associate Professor of Electrical Engineering, University of Dayton; W. J. Mayo-Wells is a consultant with the National Bureau of Standards.

MANPOWER

Scientific Manpower, 1958. Papers of the 7th Conference on Scientific Manpower; Symposium on Demographic and Sociological Aspects of Scientific Manpower. (NSF 59-37). Washington, National Science Foundation, 1959. 87 pp.

MATERIALS

Internal Stresses and Fatigue in Metals. Proceedings of the Symposium on Internal Stresses and Fatigue in Metals, Detroit and Warren, Mich., Sept. 4, 5, 1958. Edited by Gerald M. Rassweiler and William M. Grube. Amsterdam and New York, Elsevier Publishing Co.; Princeton, N.J., D. Van Nostrand Co., Inc., 1959. 451 pp., illus., diagrs., tables. $11.

Contents: *Part 1, Concepts and Significance of Internal Stresses*. Engineering Interest in Internal Stresses, R. F. Thomson. Scientific Interest in Internal Stresses, C. S. Barrett. Scope and Limitations of the Continuum Approach, J. D. Eshelby. Causes and Effects of Internal Stresses, E. Orowan.

Part 2, Crystal Lattices, Imperfections, and Stresses. Determination by X-Rays of Internal Strains in Metals and Alloys, A. Guinier. X-Ray Measurement of Residual Stresses in Hardened Steel, R. E. Marburger and D. P. Koistinen. Internal Stresses Induced by Phase Transformations, D. P. Koistinen and R. E. Marburger. Origins of Electron Interference Effects in Thin Crystals, H. M. Bendler. Observations of Dislocations in Metals, P. B. Hirsch. Dislocations and Deformation Phenomena in Iron Whiskers, R. V. Coleman. Dislocation Patterns in Deformed Alpha-Brass, A Contributed Discussion by H. G. F. Wilsdorf. Internal Strains, A Contributed Discussion by J. Nutting. Internal Stresses and Ultrasonic Measurements, A Contributed Discussion by Rohn Truell. The Study of Metal Surfaces by the Field Ion Microscope, A Contributed Discussion by Erwin W. Müller, Walter T. Pimbley, and Joseph F. Mulson.

Part 3, Dislocations, Internal Stresses, and Fatigue. Interactions and Internal Strains, J. Friedel. Nucleation and Growth of Fatigue Cracks, Earl R. Parker and Desmond M. Fegredo. Residual Stress, Strain Hardening and Fatigue, T. J. Dolan. Surface Condition and Fatigue Strength, Max R. Hempel. Effect of Residual Stresses Induced by Strain Peening upon

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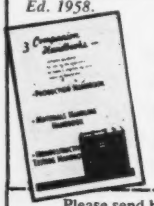

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Structure and Properties of Thin Films. Proceedings of an International Conference Held at Bolton Landing, N.Y., Sept. 9–11, 1959. Sponsored by AFOSR, ARDC, and General Electric Research Laboratory, Schenectady, N.Y. Edited by C. A. Neugebauer, J. B. Newkirk, and D. A. Vermilyea. New York, John Wiley & Sons, Inc., 1959. 561 pp., illus., diagrs., tables. $15.

The 42 papers and discussion presented in this volume reflect the increasing amount of effort expended on fundamental studies of matter in the form of thin films. Examples of investigation of the bulk properties of matter include studies of phase transformations, chemical reactivities, superconductivity, electrical resistance, Hall effect, magnetic properties, and magnetoresistance. The physical states of films that have properties not exhibited by the same material in bulk form are also discussed. Also included are papers concerned with the problems of growth and characterization of thin films—for example, direct observation of defects, structure studies including low energy electron diffraction, measurements of specific surface area, and observations of the state of stress in films. Another group deals with surface chemistry. The volume closes with a few theoretical papers on epitaxial relationships, the manner in which stresses are introduced, the interactions of atoms at surfaces, and a panel discussion on the theory of surfaces.

The editors are all with the Metallurgy and Ceramics Department Research Laboratory, General Electric Company.

Analysis of Deformation; Vol. 4, Waves and Vibrations. Keith Swainger. New York, The Macmillan Co., 1959. 370 pp., diagrs., tables. $15.

Volume 1 of this series formulated the mathematically linear theory for analyzing deformation and drew general inferences without solving the equations and boundary conditions for particular cases. In this volume the theory is applied, and the available experimental evidence is examined for the propagation of stress through, and on the surface of, substances possessing various physical properties such as elasticity, plasticity, and fluidity, and combinations of these effects. Chapter 10 presents a unified mechanistic theory of the cause of earthquake waves, volcanoes, the crustal features of the earth, the formation of lunar craters, and solar disturbances.

Dr. Swainger was recently with Imperial Chemical Industries and is now a Research Fellow in the University of London.

Tantalum and Niobium. G. L. Miller. Metallurgy of the Rarer Metals, Vol. 6. London, Butterworths Scientific Publications; New York, Academic Press, Inc., 1959. 767 pp., illus. diagrs., tables. $21.

The chemical processing of the metals is described from the decomposition of the ores to separation and purification; from the Marignac process to modern liquid-liquid techniques. While the main part of the text deals with the pure metals, the production of their alloys and the more important compounds is also explained. The applications of the metals, alloys, and compounds are catalogued in detail, and include tantalum for electrolytic capacitors, tantalum carbide for hard metals, and niobium for nuclear and high-temperature application. There is also a long chapter devoted to theoretical and other considerations of binary alloy systems.

The author is with the Research Laboratories of Murex Limited.

MATHEMATICS

Advanced Engineering Mathematics. C. R. Wylie, Jr. 2nd Ed. New York, McGraw-Hill Book Co., Inc., 1960. 696 pp., diagrs., tables. $9.00.

The present edition, although the material has been completely rewritten and brought up to date, retains the objective of the 1951 issue: to provide an introduction to those branches of mathematics with which the average analytical engineer or physicist must be reasonably familiar. There are two entirely new chapters on determinants and matrices and on finite differences. A lengthy appendix devoted to review material and a chapter on fluid mechanics, both of which appeared in the first edition, have been eliminated.

The author is Professor and Chairman, Department of Mathematics, University of Utah.

NUCLEAR ENERGY

Nuclear Radiation Engineering; An Introduction. F. W. Hutchinson. New York, The Ronald Press Co., 1960. 155 pp., diagrs., tables. $6.00.

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POWER PLANTS

Design and Performance of Gas Turbine Power Plants. Editors, W. R. Hawthorne and W. T. Olson. (High Speed Aerodynamics and Jet Propulsion, Vol. 11.) Princeton, N.J., Princeton University Press, 1960. 563 pp. illus., diagrs., tables. $15.

Contents: General Considerations, W. R. Hawthorne. Requirements and Processes, P. Lloyd. Experimental Techniques, H. C. Hottel and G. C. Williams. Fuel Injection, A. Radcliffe. Flame Stabilization, J. H. Childs. Mixing Processes, C. C. Graves and W. E. Scull. Fuels for Aircraft Gas Turbine Engines, L. C. Gibbons. Combustion Chamber Development, W. T. Olson. Mechanics of Materials for Gas Turbine Applications, E. Orowan and C. R. Soderberg. Flutter Problems in Gas Turbines, J. R. Schnittger. Performance, D. H. Mallinson and S. J. Moyes. Index.

Rocket Propulsion. Marcel Barrère, Andrè Jaumotte, Baudouin Fraeijs de Veubeke, and Jean Vandenkerckhove. Amsterdam and New York, Elsevier Publishing Co; Princeton, N.J., D. Van Nostrand Co., Inc., 1960. 829 pp., illus., diagrs., tables. $27.

This book is a completely revised and enlarged English edition of *La Propulsion par Fusées*, which was published in French, simultaneously in France and Belgium, in 1957. It deals with the fundamental problems of rocket propulsion rather than with detailed descriptions of missile or rocket construction. The text, though, touches on many fundamental questions of missile design which have an influence on the design of the rocket proper—for example, the problem of guidance of ballistic missiles.

The authors are, in the order given above, Head, Research Division, National Office for Aeronautical Studies and Researches (ONERA), Paris; Professor at the University of Brussels; Professor at the Universities of Liège and Louvain; and Lecturer at the Institute of Aeronautics, University of Brussels.

Contents: List of Symbols. 1, Rocket Propulsion Elements. 2, Nozzle Theory and Characteristic Parameters. 3, Aerothermochemistry of the Combustion Products. 4, Solid Propellants. 5, Internal Ballistics of Solid-Propellant Rockets. 6, Design of Solid-Propellant Rockets. 7, Liquid-Propellant Rockets. 8, Experimental Techniques for Rocket Propulsion. 9, Liquid Propellants. 10, Combustion Instability in Liquid-Propellant Rocket Motors. 11, Elementary Problems of Overall Rocket Performance. 12, Variational Methods in Optimizing Rocket Performance. Author Index. Subject Index. Unit Conversion Tables.

SCIENCE

Federal Funds for Science; 8, The Federal Research and Development Budget, Fiscal Years, 1958, 1959, and 1960. National Science Foundation. (NSF 59-40.) Washington, Supt. of Documents, 1959. 74 pp. $0.45.

SPACE TRAVEL

Soviet Space Science. Ari Shternfeld. 2nd Rev. and Extended Ed. Translated by the Technical Documents Liaison Office, Wright Patterson AFB, Ohio. New York, Basic Books, Inc., 1959. 361 pp., illus., diagrs., tables. $6.00.

This book was first published in Moscow in 1958 under the title of *Iskustvennye Sputniki (Artificial Satellites)*. The author, who has written on astronautics for several decades, has included an account of the launching of Sputniks I and II. Willy Ley has provided an epilogue briefly describing Sputnik III and Mechta. The treatment is descriptive and popular rather than mathematical.

Contents: 1, The Laws of Motion of Artificial Satellites. 2, Motion of the Satellite Relative to the Observer on Earth. 3, The Rocket Starter of the Artificial Satellite. 4, Launching of an Artificial Satellite. 5, Construction of Artificial Satellites. 6, Man in Cosmic Space. 7, On Board an Artificial Satellite. 8, Observation of Artificial Satellites and Their Communication with the Ground. 9, The Descent to Earth. 10, Artificial Satellites of Bodies of the Solar System. 11, The Utilization of Artificial Satellites. Appendix. Epilogue. Conversion Tables. Index.

Space Flight; Vol. 1, Environment and Celestial Mechanics. Krafft Ehricke. Princeton, N.J., D. Van Nostrand Co., 1960. 513 pp., illus., diagrs., tables. $14.50.

This is the first of three projected volumes devoted to space flight by the Program Director, Centaur-Vega Project of Convair (Astronautics), for inclusion in the series entitled *Principles of Guided Missile Design*, edited by Grayson Merrill.

The first part of Volume 1 discusses the concept of space flight and the environment in which space flight will take place, to the extent that we know it at this time. Missiles are shown to be of tremendous importance to this concept, particularly as tools for exploration beyond the initial phases of space travel. The earth with its large moon is considered to be an ideal training field for man's space capability since, in the earth-moon system, practically all important conditions to be encountered in later interplanetary operations can be simulated. The utility aspects of space flight are thoroughly discussed, and, for a more complete understanding of the environment in which space flight will take place, the author delves into our solar system from the viewpoint of the astronautical engineer, with emphasis on useful tables of consistent data.

Part 2 is devoted exclusively to celestial mechanics, once again from the viewpoint of the astronautical scientist rather than the astronomer. Therefore, emphasis is placed on those aspects which are of particular or potential importance in the orbital dynamics of space vehicles. The subject is divided accordingly. The three chapters of the second part deal consecutively with the central force field, orbit determination, and perturbation analysis—the three areas that form the foundation of space flight mechanical performance analysis, tracking or on-board position determination, and precision navigation.

Space Flight is written for the serious student of astronautics with the aim of assisting the reader in research and development work, preliminary design, and systems analysis. To this end, a number of problems which can be solved by hand calculation (as opposed to computer calculation) and short-cut methods are listed at the end of each chapter on celestial mechanics.

Advances in Space Science, Vol. 1. Edited by Frederick I. Ordway, III. New York, Academic Press, 1959. 412 pp., illus., diagrs., tables. $12.

Contents: Interplanetary Rocket Trajectories, D. F. Lawden. Interplanetary Communications, J. R. Pierce and C. C. Cutler. Power Supplies for Orbital and Space Vehicles, J. H. Huth. Manned Space Cabin Systems, E. B. Konecci. Radiation and Man in Space, H. J. Schaefer. Nutrition in Space Flight, R. G. Tischer. Appendix: A Decimal Classification System for Astronautics, H. H. Koelle.

STRUCTURES

The Theory of Thin Shells. V. V. Novozhilov. Translated by P. G. Lowe. Edited by J. R. M. Radok. Groningen, The Netherlands, P. Noordhoff Ltd., 1959. 376 pp., diagrs., tables. $9.50.

This is a translation of *Teoriia Tonkikh Obolochek*, Moscow, 1951. It is divided into four chapters, the first of which is devoted to the general (moment) theory of thin shells; the second, to the membrane (momentless) theory; and the third and fourth, to the moment theory of two types of shells which are important in industrial applications—cylindrical shells and shells of revolution. The problem, as treated in the book, is a linear one—i.e., displacements are assumed to be small in comparison with the thickness of the shell and the strains are not to exceed the limit of proportionality.

UPPER ATMOSPHERE RESEARCH

The Use of High-Altitude Rockets for Scientific Investigations; An Annotated Bibliography. Compiled by Mildred Benton. (Bibliography No. 16.) Washington, Library Branch, Technical Information Division, U.S. Naval Research Laboratory, Oct., 1959. 123 pp.

The period covered is 1946 to June, 1959. Both domestic and foreign periodical articles and reports are included. The 965 references are listed by author or issuing agency in the grouping for each year. There are author and subject indexes.

✦ ✦ ✦

Letters *(Continued from page 108)*

and applying this, we have

$$V_a \cos \gamma_1 = 0$$

Since V_a is nonzero, this relation calls for $\gamma_1 = 90°$, which is the correct optimum solution. It is thus seen that Kelley's concluding remark is quite incorrect, and that, therefore, the thesis which he presents is also incorrect.

To make this point even clearer, we may write that at any time

$$g = g_0(R_e/h_a)^2$$

$$F_e = \dot{m} V_{ex}$$

$$h_G = h_a + R_e$$

so that if each of these conditions were proper restraints, we would have to introduce them to the integrand in the form

$$\lambda_a[g - g_0(R_e/h_a)^2] + \lambda_b[F_e - \dot{m} V_{ex}] + \lambda_c[h_G - h_a + R_e]$$

We think that such an introduction constitutes a *reductio ad absurdum* of the extraneous multiplier concept since we can think of no limit to the various definitions which might be introduced into any variational integrand were we actually free to do this *ad nauseum*. The fact is that we are not at liberty to do this any more than we are at liberty to postulate degrees of freedom which do not exist.

We therefore state that those restraints required to ensure physically real solutions (*and only those restraints*) are permissible in variational problems. Moreover, the use of extraneous restraints can have no effect other than to restrict the optimum solution domain.

Daniel O. Dommasch, AFIAS

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